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Aircraft Emission Inventories Projected in Year 2015 for a High Speed Civil Transport (HSCT) Universal Airline Network

Steven L. Baughcum and Stephen C. Henderson

Contract NAS1-19360
Prepared for Langley Research Center

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Executive Summary

This report describes the development of a database of aircraft fuel burned and emissions from projected fleets of high speed civil transports (HSCTs) on a universal airline network. Inventories for 500 and 1000 HSCT fleets were calculated. Inventories of Year 2015 subsonic aircraft fleets in service with these HSCT fleets were also calculated. These emissions inventories were developed under the NASA High Speed Research Systems Studies (HSRSS) contract NAS1-19360, Task Assignment 40.

The objective of this work was to evaluate the changes in geographical distribution of the HSCT emissions as the fleet size grew from 500 to 1000 HSCTs. For this work, a new expanded HSCT network has been used and flights projected using a market penetration analysis rather than assuming equal penetration (as was assumed for the emission scenarios developed for the 1993 AESA assessment). Emission inventories on this network were calculated for both Mach 2.0 and Mach 2.4 HSCT fleets with NOx cruise emission indices of approximately 5 and 15 grams NOx/kilogram fuel.

These emissions inventories will be available for use by atmospheric scientists conducting the Atmospheric Effects of Stratospheric Aircraft (AESA) modeling studies. Fuel burned and emissions of nitrogen oxides (NOx as NO_2), carbon monoxide, and hydrocarbons have been calculated on a 1 degree latitude x 1 degree longitude x 1 kilometer altitude grid and delivered to NASA as electronic files. This report describes the assumptions and methodology for the calculations and summarizes the results of these calculations.

The work presented here shows that the total global fuel burned and emissions from a fleet of 500 HSCTs is not very different whether the expanded HSCT network or the 1993 AESA assessment network is used. The geographical distribution of emissions at stratospheric cruise is sensitive to the market penetration assumptions used to distribute projected HSCT passenger demand.

An increase in HSCT fleet size from 500 to 1000 units has been shown to approximately double emissions at stratospheric cruise. However, as the fleet grows, emissions in different geographical regions grow at different rates. Consequently, stratospheric emissions in northern mid-latitudes are not projected to double as the fleet size doubles, while emissions in the northern tropics and southern hemisphere mid-latitudes are expected to more than double.

For an HSCT combustor with a NOx emission index of 5, the analyses show that the total NOx emissions below 13 kilometers altitude are not very sensitive to the presence or absence of an HSCT fleet. This suggests that to first-order the assessment of the effects of an HSCT fleet are largely decoupled from the assessment of subsonic aircraft effects.

During this work, we discovered several errors made in our previous study (NASA CR 4592) and present the corrected data in this report. For the HSCT, it was found that the operating empty weight used in the emission scenario calculation had been incorrectly entered into the analysis data file and was not consistent with the performance data for the baseline model used in the study. This was corrected and revised emission inventories for Mach 2.0 and Mach 2.4 HSCTs on the 1993 AESA assessment network were calculated, delivered to NASA Langley, and described in this report. The fuel burned for the revised Mach 2.4 HSCT scenario on the 1993 AESA assessment network increased by 7% and the cruise altitude decreased by about 1100 feet when compared with the results presented earlier in NASA CR 4592. In addition, the fuel performance improvement factor for the very large aircraft (P900) projected for 2015 was incorrectly implemented. This was corrected and revised 2015 subsonic aircraft emission scenarios are described in this report. This correction increased the total projected fuel burned by a future all subsonic fleet by 2 %, well below the uncertainty in projected future emissions.

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GLOSSARY

AEAP	Atmospheric Effects of Aviation Project
AESA	Atmospheric Effects of Stratospheric Aircraft
APU	Auxiliary power unit
ASM	Available seat mile (the number of seats an airline provides times the number of miles they are flown)
ATC	Air traffic control
ATM	Available ton-miles (the number of tons capable of being carried times the number of miles flown)
BCAG	Boeing Commercial Airplane Group
BMAP	Boeing Mission Analysis Process
CO	Carbon Monoxide
CO_2	Carbon Dioxide
EI(CO)	Emission Index (grams CO/kg fuel burn)
EI(HC)	Emission Index [grams hydrocarbon (as CH_4)/kg fuel burn]
EI(NOx)	Emission Index (grams NOx (as NO_2)/kg fuel burn)
FAA	Federal Aviation Administration
GAEC	Global Atmospheric Emissions Code
GCD	Great circle distance
GE	General Electric
gm	gram
HC	Unburned hydrocarbon
H_2O	Water
HSCT	High Speed Civil Transport
HSRP	High Speed Research Program (NASA)
ICAO	International Civil Aviation Organization
ISA	International standard atmosphere
kg	kilogram
lb	pound
Load Factor	Percentage of an airplane's seat capacity occupied by passengers on a given flight
LTO cycle	Landing takeoff cycle
M	Mach number
MDC	McDonnell Douglas Corporation
MTOW	Maximum takeoff weight
NASA	National Aeronautics and Space Administration
nm	Nautical mile
NOx	Oxides of nitrogen (NO + NO_2) in units of gram equivalent NO_2
OAG	Official Airline Guide
OEW	Operating Empty Weight
P&W	Pratt & Whitney
PAX	passengers
RAM	Revenue air mile
RPM	Revenue passenger miles (the number of paying passengers times the number of miles they fly)

RTM	Revenue ton-miles (number of tons carried times the number of miles flown)
SO_2	Sulfur dioxide
TBE	Turbine bypass engine
TOGW	Takeoff gross weight
ton	2000 pounds
3D	Three dimensional

1. Introduction

A major goal of the NASA High Speed Research Program (HSRP) and of the Boeing High Speed Civil Transport (HSCT) program is to design an HSCT that will not cause a significant impact on the stratospheric ozone layer. To help achieve that goal, NASA has funded the Atmospheric Effects of Stratospheric Aircraft (AESA) project to assess the effect of a fleet of commercial supersonic transports on the atmosphere. To support that assessment, Boeing was contracted to calculate three-dimensional inventories of emissions from fleets of HSCTs. Scenarios of projected subsonic air traffic, both with and without HSCT fleets, were also calculated for use in the atmospheric assessment. Both HSCT and subsonic fleets were projected for the year 2015.

Earlier projections of HSCT emission inventories used in the 1993 AESA assessment were based on an average of Boeing and McDonnell Douglas forecasts to project future passenger demand. (Baughcum, *et. al.*, 1994; Wuebbles, *et. al.*, 1993; Landau, *et. al.*, 1994) Simple ground rules were defined to identify the accessible HSCT market and to create projected departure schedules. Market penetration (the proportion of the passenger demand captured by the HSCT) was assumed to be equal for all HSCT city pairs. Emission scenarios were calculated for Mach 2.0 and Mach 2.4 HSCT fleets by Boeing (Baughcum, *et. al.*, 1994) and for Mach 1.6 by McDonnell Douglas. (Landau, *et. al.*, 1994)

Two-dimensional modeling calculations have shown that the HSCT impact on the ozone layer depends on both the amount of NOx emissions injected into the stratosphere and on the HSCT flight altitudes. (Albritton, *et. al.*, 1993; Stolarski and Wesoky, 1993). More recent calculations have shown that the calculated impact depends on the geographical location as well. (Considine, *et. al.*, 1995) Their model predicts that flights in the tropics will have a much larger impact than flights at mid-latitudes. Thus, in developing emission scenarios, it is important that we realistically project the geographical location of future flights, as well as the total quantity of emissions. It is also important that we understand how sensitive these geographical distributions of emissions are to our assumptions about the HSCT market.

The work presented herein is an extension of the earlier Boeing work (Baughcum, *et. al.*, 1994) of scheduled air traffic emissions. For this study, the Boeing baseline forecast (Boeing, 1993) of passenger demand has been projected to year 2015. A new HSCT route system and schedule have been developed with HSCT passenger demand calculated via a market penetration analysis, rather than assuming that penetrations of all markets will be equal. The flights were then scheduled assuming a single universal airline. As with the previous study, it was assumed that the HSCT would fly supersonically only over water.

The work presented here is for fleets of approximately 500 and 1000 HSCTs in active flight operations. (The total number manufactured would be higher to account for maintenance, inspections, etc.)

Future fleets of HSCTs must be able to compete economically with subsonic aircraft; so,the HSCT will be utilized on routes which can take advantage of its speed. Since it is anticipated that the HSCT will only fly supersonically over water, this means that some routes will be more attractive than others. In this study, the HSCT market capture for flights between individual cities is calculated explicitly taking into account the time saved by supersonic flights. It is believed that this will give a more realistic geographical distribution of future HSCT emissions than was obtained with the scenarios calculated for the 1993 AESA assessment, which assumed equal market penetration for all city pairs which satisfied certain simple ground rules.

In order to evaluate how growth of an HSCT fleet would alter the geographical distribution of HSCT emissions used in the AESA assessments, schedules corresponding to the passenger demands of approximately 500 and 1000 active HSCTs were created. The emission inventories developed from these schedules can then be used to evaluate how parametric changes in fleet size affect the HSCT impact on the stratospheric ozone layer.

Fuel consumption and emissions of nitrogen oxides (NOx), carbon monoxide (CO), and hydrocarbons (HC) were calculated for all flight segments and are reported on a three-dimensional grid with a resolution of 1 degree latitude x 1 degree longitude x 1 km altitude. Given the fuel burned in each grid cell, emissions of water vapor, carbon dioxide, and sulfur dioxide can be determined from the fuel properties. The following scenarios were calculated:

- Projected 2015 HSCT traffic for 500 and 1000 Mach 2.4 HSCTs with nominal NO_x emission indices of 5 and 15 gm NO_x/kg fuel burned at cruise.
- Projected 2015 HSCT traffic for Mach 2.0 HSCTs with nominal NO_x emission indices of 5 and 15 gm NO_x/kg fuel burned at cruise (passenger demand corresponding to 500 and 1000 Mach 2.4 HSCTs).
- Projected 2015 scheduled subsonic aircraft (assuming no HSCT fleet exists).
- Projected 2015 scheduled subsonic aircraft (assuming an HSCT fleet with passenger demand corresponding to 500 Mach 2.4 HSCTs was flying).
- Projected 2015 scheduled subsonic aircraft (assuming an HSCT fleet with passenger demand corresponding to 1000 Mach 2.4 HSCTs was flying).

The fuel burned and emission characteristics of the HSCT and future subsonic aircraft were based on estimated performance. The HSCT performance and emissions were the best estimate available at the beginning of this study and were "frozen" in order to develop new emission scenarios in time for the 1995 AESA assessment. Since then, preliminary design work has continued on both the airframe and the engine. The final design of the HSCT will likely have some characteristics different from those assumed for this study; hopefully, it will be more fuel efficient. The HSCT emission projections are based on the HSRP program goal and the estimates of the engine companies and are treated parametrically in this study and in the AESA assessment. As combustor rig test data becomes available, it will be possible to better refine these projections.

The details of the emission calculation process are described in NASA CR-4592 (Baughcum, *et. al.*, 1994) and will only be summarized in this report. The results obtained in this study are compared with the emission scenarios calculated for the 1993 AESA assessment (Baughcum, *et. al.*, 1994). The effects of fleet growth on the geographical distribution of HSCT emissions are analyzed and discussed.

During this work, we discovered several errors made in our previous study and present the corrected data in this report. For the HSCT, it was found that the operating empty weight used in the emission scenario calculation had been incorrectly entered into the analysis data file and was not consistent with the performance data for the baseline model used in the study. This was corrected and revised emission inventories for Mach 2.0 and Mach 2.4 HSCTs on the 1993 AESA assessment network were calculated, delivered to NASA Langley, and described in this report. In addition, the fuel performance improvement factor for the very large aircraft (P900) projected for 2015 was incorrectly implemented. This was corrected and revised 2015 subsonic aircraft emission scenarios are described in this report.

The work on HSCT and Year 2015 emission scenarios described in this report was conducted under NASA Langley Contract NAS1-19360, Task 40. The NASA Langley Task Manager was Donald L. Maiden.

Within the Boeing HSCT engineering group, overall program management was provided by Thomas Derbyshire, John D. Vachal, and John H. Gerstle. The principal investigator of the task was Steven L. Baughcum. Chief contributors were Stephen C. Henderson, Terry Higman, Thomas T. Odell, and Richard Bateman in market analysis; Peter S. Hertel in computer support; and Debra R. Maggiora in data analysis.

2.0 New Expanded HSCT Network

2.1 Total Passenger Demand Forecast for 2015

The total passenger demand forecast for the year 2015 was created by escalating 1991 reported regional flow passenger demand data using the annual growth rates developed by Boeing and published in the 1993 Current Market Outlook (Boeing, 1993). This yearly publication shows the Boeing Commercial Airplane Group's traffic and airplane demand forecasts. The results of this forecast, including regional flow growth rates and passenger demand (revenue passenger miles or RPMs), are summarized in Table 2-1 below. A more detailed table of the passenger demand for each of the forecast regions is shown on Appendix A, with the interim years of 1995, 2000, 2005 and 2010 also shown, along with the interim year-to-year growth rates.

Table 2-1. World Traffic Forecast

Regional Flow	1991 RPMs (millions)	Average Annual Growth Rate 1991-2015	2015 RPMs (millions)
Intra & Domestic N. America	358,741	4.01%	921,565
N. America-Europe	121,400	4.78%	372,129
N. America-Asia/Pacific	87,065	7.03%	445,013
Other N. America	3,565	4.08%	9,306
N. America-Latin America	36,476	5.20%	123,092
Intra & Domestic Europe	148,216	4.62%	437,999
Europe-Asia/Pacific	46,430	8.05%	297,690
Europe-Indian Sub Continent	9,718	3.54%	22,376
Europe-Mid East	19,578	5.07%	64,163
Europe-Africa	25,811	4.48%	73,850
Europe-Latin America	26,869	5.34%	93,627
Intra & Domestic Asia/Pacific	86,003	7.92%	535,482
Misc. Long Range	40,348	5.70%	152,698
Japan	33,773	4.16%	89,918
Intra & Dom Indian Sub Continent	6,779	5.81%	26,316
Other Indian Subcontinent	14,261	4.75%	43,461
Intra & Domestic Mid East/Africa	18,455	5.01%	59,695
Other African	8,002	5.38%	28,163
Intra & Domestic Latin America	27,023	5.26%	92,463
CIS International	13,842	3.70%	33,098
MAC Charter	5,657	-2.36%	3,191
Total	1,138,012	5.29%	3,925,296

2.2 HSCT Universal Route System

The "Universal" HSCT route system is meant to simulate the operation of HSCTs as a mature fleet in a global airline network. The "Universal" system can be considered the sum of several global airlines, although it it scheduled as if it is a single airline. This approach can be justified by making the assumption that in the future, airline alliances and code-sharing will be more extensive than today (particularly among international airlines).

A "Universal" HSCT route system was originally developed as part of the 1993 AESA HSCT assessment (Baughcum, *et. al.*, 1994). The route system used in this study is based on the original system, but has been enlarged and refined to add many more city-pairs and to provide more efficient land-avoiding flight tracks. Gateway cities were established in the countries of each of the regions included in the regional traffic flow forecasts and assumed to be the focus of HSCT flights in year 2015. Thus HSCT flights from Britain are assumed to operate from London, flights from France operate from Paris, etc. Some countries were given more than one gateway city, due to the size of the market and/or the size of the country. (For example, the United States has 18 gateways, Japan 2 gateways, Australia and Germany 3 gateways each)

A list of the assumed gateway cities for HSCT operations is shown in Appendix B.

The total year 2015 world passenger demand (measured as passengers) was distributed among the gateway city-pairs in each region by using the share of the total passenger available seat miles (ASM) that each city pair included in the regional flows generated in 1993 (as derived from the Official Airline Guide schedules). For each city-pair in each region, total passenger demand in 2015 was forecast as follows:

$$\text{Passenger Demand}_{\text{CITY-PAIR, 2015}} =$$

$$(\text{RPM}_{\text{REGIONAL FLOW, 2015}} \times (\text{ASM}_{\text{CITY-PAIR}}/\text{ASM}_{\text{REGION}})_{1993})/\text{Distance}_{\text{CITY-PAIR}}$$

2.3 HSCT Passenger Traffic Demand - Market Penetration

Due to the operating characteristics of the HSCT (sonic boom restrictions and high operating costs, particularly on short routes), only a certain subset of the total regional passenger demands are candidates for HSCT service. (U.S. Domestic, Intra Europe, and the domestic demand of other regions are excluded, for example). The suitability of the HSCT for the remaining passenger demand must be determined according to some logical assessment criteria.

In the previous 1993 AESA HSCT emission database study (Baughcum, *et. al.*, 1994), routes for HSCT service were selected according to a set of "static" criteria mutually agreed upon between Boeing and McDonnell Douglas. Routes were selected using the following ground rules:

- No supersonic flight over land
- Flight distance must be greater than 2000 nautical miles
- No more than 50% over land routing
- No more than 20% diversion from great circle routing
- Passenger demand must be sufficient to support at least one flight/day at 70% load factor

Once the routes that satisfied these criteria were selected, equal market penetration of the HSCT was assumed on all markets. The penetration level was adjusted to produce the 500 Mach 2.4 airplane fleet size used in that study.

One of the goals of the current fleet growth study is to determine how an increasing fleet of HSCT's would change the global distribution of emissions. Therefore, this study does not use a "static" set of criteria for determining the proportion of city-pair demand likely to be captured by the HSCT. Instead, demand captured by the HSCT is assumed to depend only on travel time saved and the fare differential over a subsonic airplane serving the same city-pair. (The travel time saved is in turn determined by the routing required to minimize flight over land, see Section 2.4.) HSCT demand capture in this study was determined by a proprietary market penetration model developed within Boeing. The proportion of each city-pair market captured by the HSCT was found by:

$$P = f(R,T,F,Z,L_{min})$$

where
P = percent of total passenger demand carried by the HSCT,
R = range of the HSCT,
T = Trip time saved versus a subsonic airplane,
F = Fare premium over the subsonic airplane,
Z = stop factor (whether the HSCT flight is non-stop or not), and
L_{min} = the minimum load factor allowed on a flight.

The only explicit constraint operating in the penetration model is the prohibition of supersonic flight over land.

As the amount of time saved increased or the fare premium decreased, or the number of stops decreased, the proportion of the passenger demand carried by the HSCT increased. If the application of the penetration model lowered the HSCT passenger demand on a city-pair to less than 180 passengers per day, that city-pair was dropped from the HSCT system. The fare premium parameter (F) of the model was first adjusted so that the passenger demand carried by the HSCT in 2015 required approximately 500 Mach 2.4 airplanes, forming the baseline case for the calculation of HSCT emissions distribution. The fare premium parameter was then reduced so that the increased passenger demand required approximately 1000 Mach 2.4 airplanes, creating the alternate case. The average load factor was 65%.

The higher demand carried by the 1000 airplane fleet came from both an increased penetration on the same markets served by the 500 airplane fleet and an increase in the number of city-pairs served. The city-pairs, number of departures and other system data are listed in Appendix C for the 500 and 1000 unit HSCT fleets. The route system maps for fleets of 500 and 1000 HSCTs are shown in Figures 2-1 and 2-2, respectively. The routes added as the fleet grew from 500 to 1000 are shown in Figure 2-3.

Emission inventories of HSCT airplanes designed with cruise speeds of Mach 2.0 using the same route systems defined by the Mach 2.4 airplanes were also calculated. Passenger demand levels and route systems which required nominally 500 (actually 499) and nominally 1000 (actually 991) Mach 2.4 airplanes required 528 and 1062 Mach 2.0 airplanes, respectively.

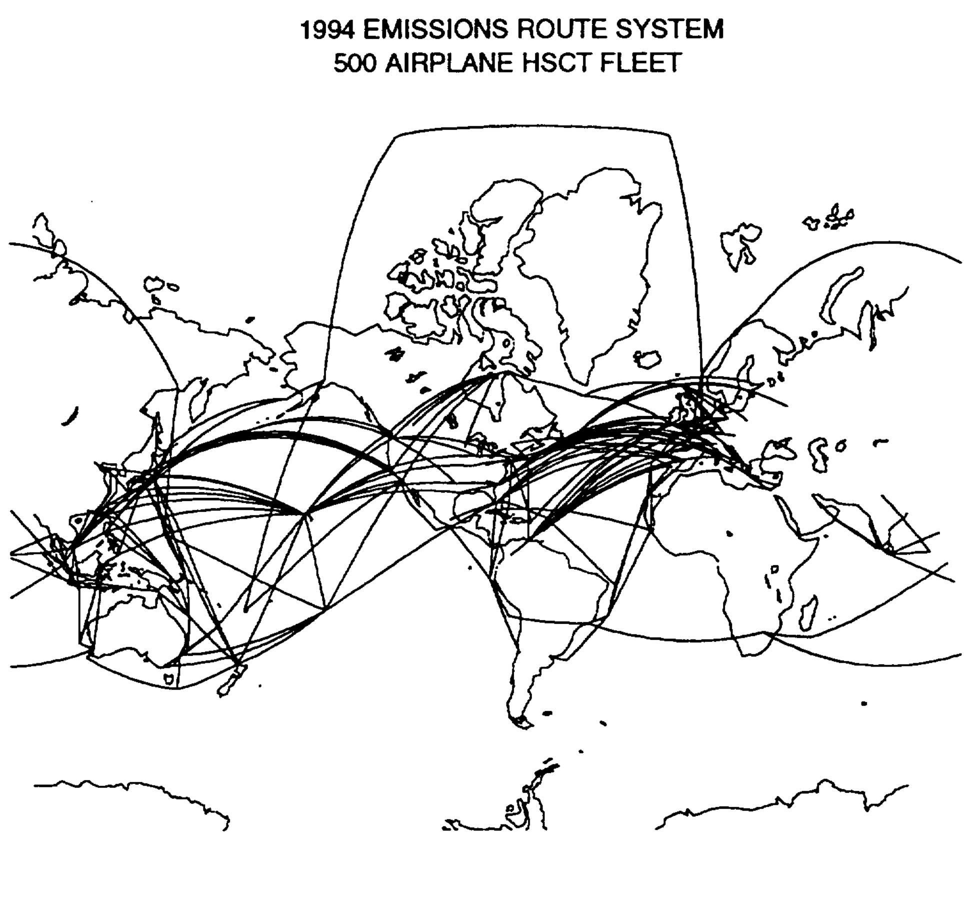


Figure 2-1. Universal Network Route System, 500 HSCT fleet

1994 EMISSIONS ROUTE SYSTEM
1000 AIRPLANE HSCT FLEET

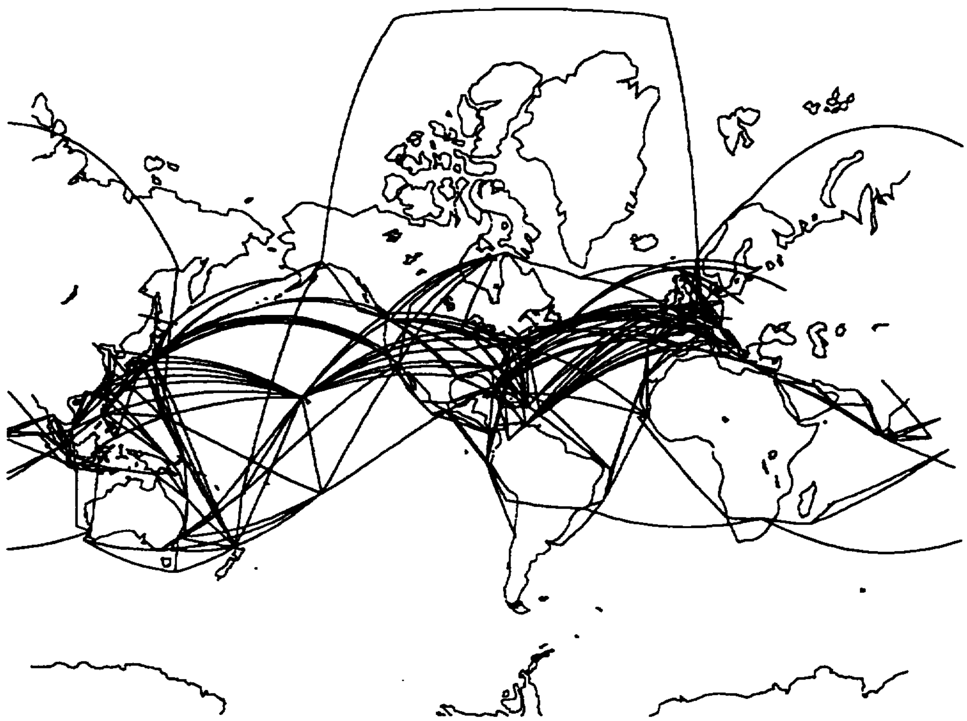


Figure 2-2. Universal Network Route System, 1000 HSCT fleet

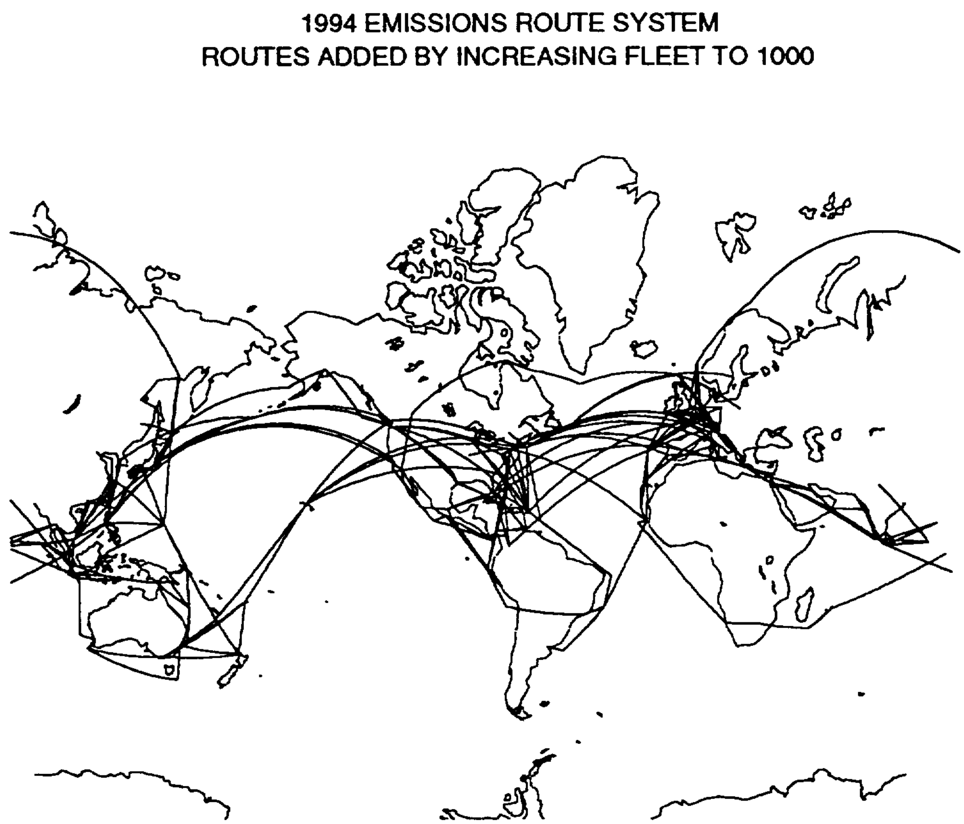


Figure 2-3. Universal Network Route System, New Routes added when increasing fleet to 1000 HSCTs.

2.4 HSCT Flight Paths - Waypoint Routing

As was noted previously, the amount of trip time saved by the HSCT versus a subsonic airplane serving the same city-pair is one of the determinants of HSCT market penetration. Since it is assumed that the HSCT must fly at subsonic speeds over land masses, each potential HSCT city-pair route was examined to find the reasonable routing which minimized (or at least reduced) the percentage of the flight spent over land. The flight routing was accomplished by establishing "waypoints", a set of specific latitude-longitude positions which defined the HSCT flight path. (The HSCT flight path between waypoints was flown as a great circle.)

As an example, consider HSCT flights from Frankfurt (FRA) to Bangkok (BKK) (See Figure 2-4). The shortest (great circle) flight path is 4841 nautical miles, all over land and therefore flown subsonically. The flight path between BKK and FRA can be altered by requiring the HSCT to fly between "waypoints", established at defined latitude-longitude positions designed to minimize the amount of overland flight. As shown in Figure 2-4, waypoints can be used to route the HSCT subsonically from Frankfurt to near Venice, then supersonically down the Adriatic, across the Mediterranean to the Sinai, subsonically across the Arabian peninsula, then supersonically again around India to Bangkok. This new path reduces the amount of flight overland to only 1993 nautical miles, but increases the total flight path to 6130 nautical miles, a distance greater than the 5000 nautical design range of the study airplane. Flying this path requires a stop at Bahrain (BAH) to refuel (and pick up passengers). After the Bahrain stop, the HSCT resumes the flight as defined above. The new path (with a stop) adds 28% to total miles flown, but reduces the subsonic flight portion of the path by 62%. (See Table 2-2)

Table 2-2. Example of waypoint routing - Frankfurt to Bangkok

Route Segment	Great Circle Distance (nmi)	Flight Path Distance (nmi)	Supersonic Distance (nmi)	Subsonic Distance (nmi)
Frankfurt - Bangkok (Great Circle Path)	4,841	4,841	0	4,841
Frankfurt - Bangkok (Direct, HSCT Waypoints)	4,841	6,130	4,137	1,993
Frankfurt - Bahrain - Bangkok (Stop at Bahrain, HSCT Waypoints)	5,292	6,181	4,319	1,862
Percent Change in Flight Path from direct Great Circle		28%		-62%

FRANKFURT - BANGKOK HSCT FLIGHT PATHS
EXAMPLE OF WAYPOINT ROUTING

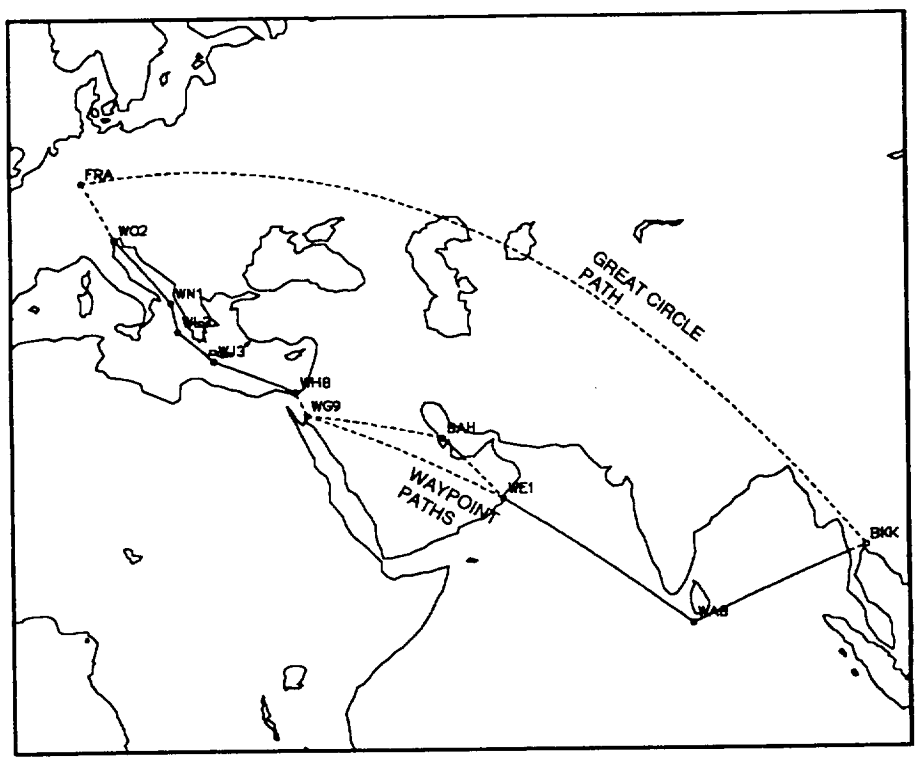


Figure 2-4. Example of Waypoint Routing

The above example shows a somewhat extreme change in flight path. Using the new waypoint routing and the market penetration model, the HSCT route system used in this study is very efficient - adding only about 5% to total route miles flown. 90% of HSCT trips are penalized less than 10% in flight path distance over the minimum Great Circle distance (Figure 2-5). 90% of HSCT trips also operate at 60% or less of subsonic block time (Block time is the total time for the flight including roll back, taxi-out, flying, and taxi-in. Subsonic block time is the block time that a subsonic aircraft would require.) Almost 60% of HSCT trips operate at less than half of subsonic block time (These statistics for for the 500 airplane fleet) (Figure 2-6). The 1000 airplane fleet, with its greater market penetration, includes more routes which are less desirable from an HSCT efficiency standpoint - lowering the overall waypoint routing efficiency and fleet time savings by a small amount. Waypoints and their positions for all HSCT routes flown are compiled as part of the flight path listing in Appendix D.

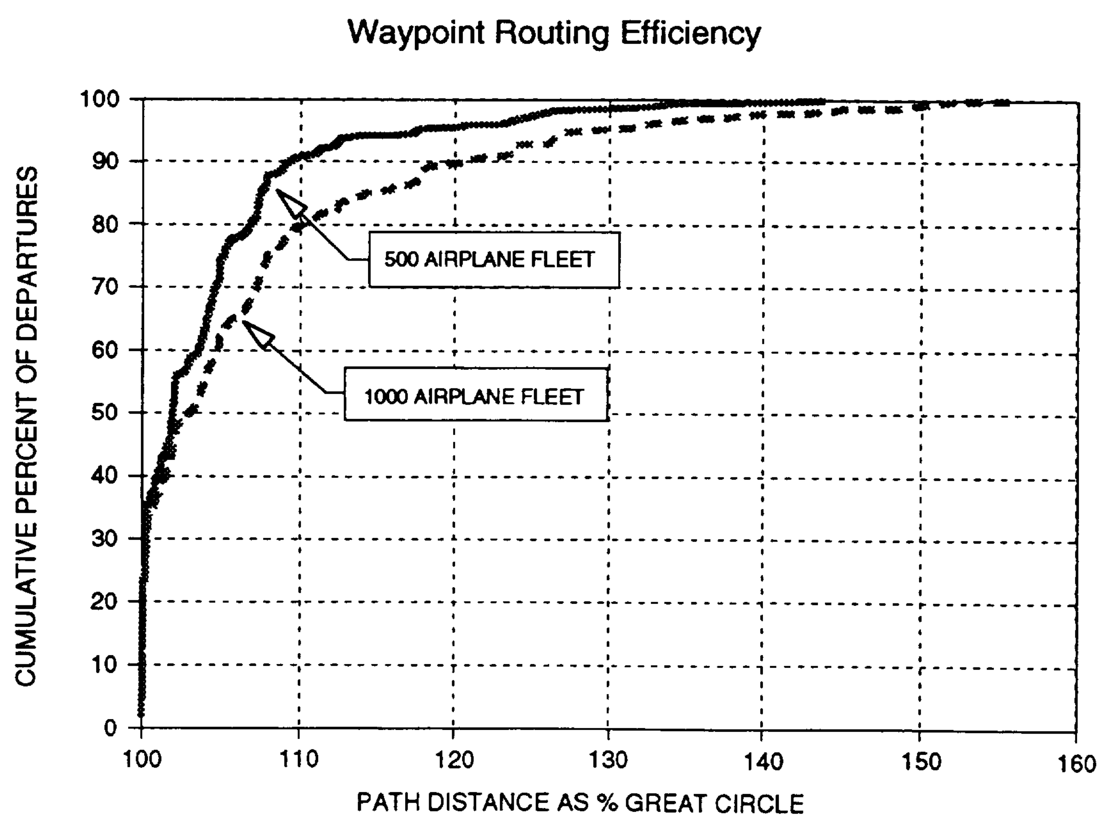


Figure 2-5 Waypoint Routing Efficiency

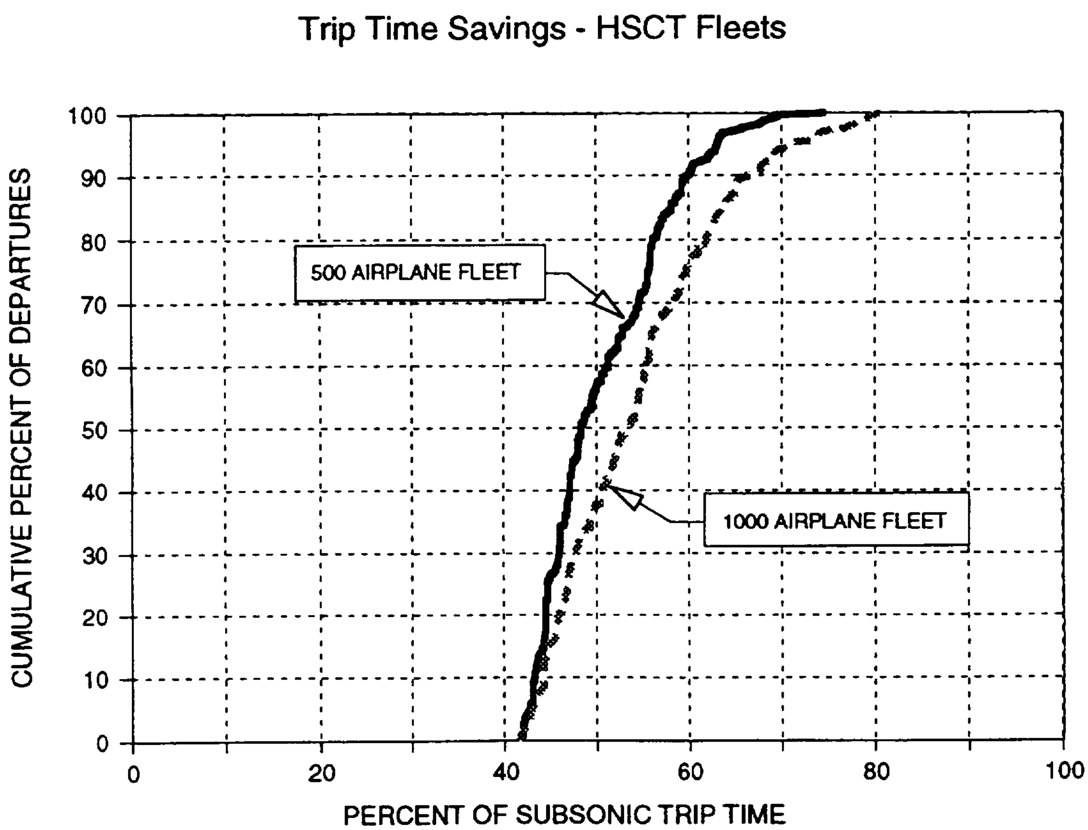


Figure 2-6 Trip Time Savings - HSCT Fleets

2.5 HSCT Scheduling

A description of the method of scheduling the HSCT fleet is provided in Appendix E. The resulting utilization statistics are summarized below. The nonlinear nature of both the penetration model and the scheduling model made it difficult to exactly achieve the goal of 500 and 1000 airplane HSCT fleets. The fleet size was adjusted by varying the fare premium in the penetration model so that the nominal "500" unit Mach 2.4 fleet was actually 499 units and the nominal "1000" unit fleet was actually 991 units. These were felt to be close enough to the target fleet sizes for these parametric studies and additional iterations were not performed.

Table 2-3. Utilization statistics for the universal airline HSCT network.

	Mach 2.4		Mach 2.0	
Units	499	991	528	1062
Average Stage Length - n.m.	3555	3026	3555	3026
Average Daily Use (hours)	21.95	22.24	21.87	22.17
Average Hours/Segment	3.67	3.30	4.07	3.62
Average Hours/Trip	4.26	3.78	4.71	4.13
Average Block Hours/Day	16.00	16.10	16.75	16.49
Percent of Subsonic Trip Time	49.97	53.25	55.21	58.28
Network Flight Path % of GCD	103.98	106.16	103.98	106.16
% of Trip in Supersonic Cruise	75.16	71.18	78.66	74.92
% of Trip in Subsonic Cruise	12.52	15.46	12.54	15.49
Percent Nonstop Trips	87.88	89.39	87.88	89.39
Average Trip Load Factor	65.16	65.09	65.16	65.09
Annual RPMs (Billion)	551	1,043	551	1,043
Annual ASMs (Billion)	846	1,602	846	1,602
Annual Departures	793,510	1,765,140	793,510	1,765,140
Annual RAMs (GCD - Million)	2,713	5,031	2,713	5,031
Annual RAMs (Path - Million)	2,821	5,341	2,821	5,341

Because of its speed, the HSCT has the ability to serve a large set of cities and still remain within the preference/curfew time "windows", which are always defined in local time.

2.6 2015 Subsonic Traffic

Subsonic air traffic for the year 2015 was projected using the passenger demand forecasts used in NASA Contractor Report 4592 (Baughcum, *et. al.*, 1994). Displacement of subsonic traffic by the HSCT passenger demand was included as described in the earlier study.

3.0 Emissions Calculation Procedure

3.1 Overview of Emissions Calculation

The primary emissions from aircraft engines are water vapor (H_2O) and carbon dioxide (CO_2) produced by the combustion of jet fuel. Nitrogen oxides (NO_x), carbon monoxide (CO) and hydrocarbons are also produced in the combustors and vary in quantity according to the temperature, pressure, and other combustor conditions. Nitrogen oxides consist of both nitric oxide (NO) and nitrogen dioxides (NO_2). Sulfur dioxide (SO_2) may also be produced due to sulfur impurities in jet fuel. Soot is also produced, particularly at high power settings, but its characterization is beyond the scope of the current work.

Emission indices of water, carbon monoxide, and sulfur dioxide are determined by the jet fuel properties. These were discussed in our previous contractor report (Baughcum, *et. al.*, 1994) and are summarized below.

Table 3-1. Recommended emission indices in units of grams emission/kilogram fuel for 1990 and 2015.

Emission	Emission Index	
	1990	2015
Carbon Dioxide (CO_2)	3155	3155
Water (H_2O)	1237	1237
Sulfur dioxide (SO_2)	0.8	0.4

The emission levels from aircraft engines are discussed by Miake-Lye (Miake-Lye, *et. al.*, 1992). The emissions are characterized in terms of an emission index in units of grams of emission per kilogram of fuel burned. For NOx, the emission index [EI(NOx)] is given as gram equivalent NO_2 to avoid ambiguity. Although hydrocarbon measurements of aircraft emissions by species have been made (Spicer, *et. al.*, 1992), only total hydrocarbon emissions are considered in this work, with the hydrocarbon emission index [EI(HC)] given as equivalent methane (CH_4).

Nitrogen oxides are produced in the high temperature regions of the combustor primarily through the thermal dissociation of oxygen followed by oxygen atom reactions with molecular nitrogen. Thus, the NOx produced by an aircraft engine is sensitive to the length of the combustor, the pressure, and the temperature within the combustor. The emissions vary with the power setting of the engine (highest at high thrust conditions). By contrast, carbon monoxide and hydrocarbon emissions are highest at low power settings when the temperature of the engine is low and incomplete combustion occurs.

Once a schedule of city-pairs and departures was determined, the next step in the development of the scenario data set was to use aircraft/engine performance and emissions data to calculate the fuel use and emissions as a function of altitude and location. For each mission, fuel consumption and emissions are calculated including all the flight segments (taxi-out, takeoff, climb, cruise, descent, landing, taxi-in), distributing the emissions in space along the route between city-pairs. The emissions were then combined for all flights into the resulting three-dimensional database.

3.2 HSCT Description

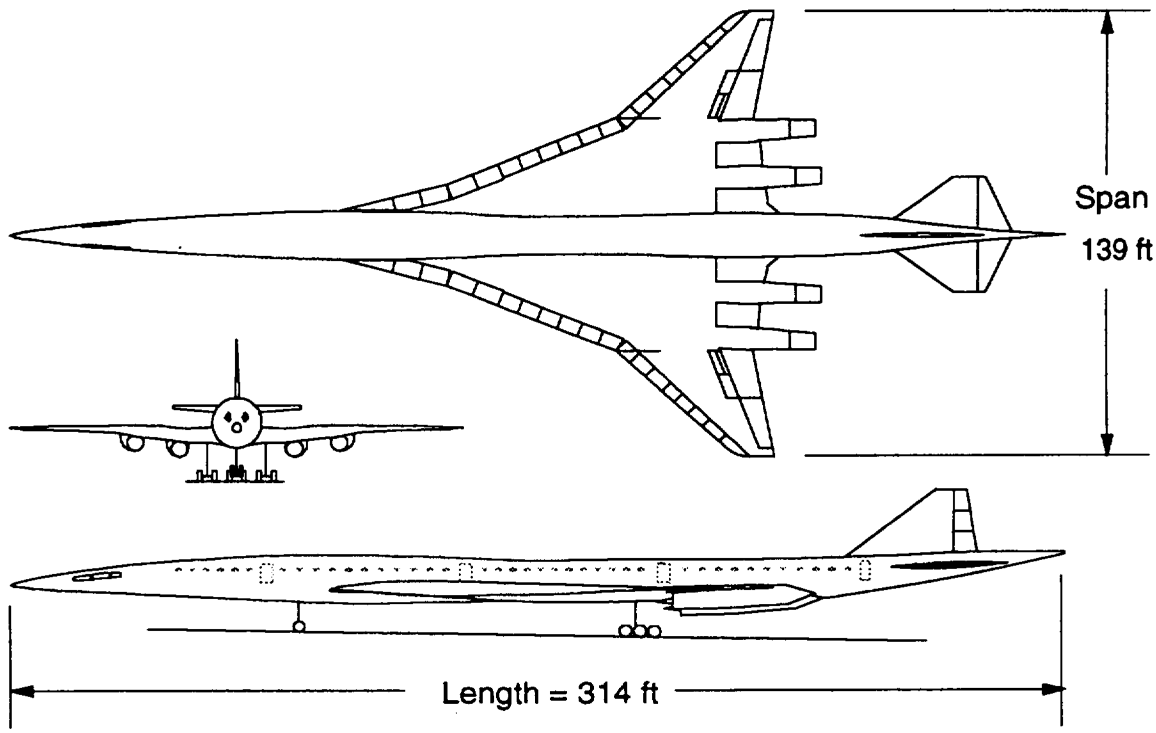
The Mach 2.4 HSCT scenarios were calculated using the Boeing preliminary design model 1080-924 with four Pratt & Whitney STJ989 turbine bypass engines (TBE) with mixed compression translating center body (MCTCB2) inlets and two-dimensional semi-stowable (SS2D) nozzles. The aircraft has a cranked-arrow wing planform (see Figure 3-1) and a mostly composite structure. Overall body length is approximately 314 feet with a wing span of 139 feet. It was designed to carry 309 passengers for a range of 5000 nautical miles.

The Mach 2.0 HSCT scenarios were developed based on the preliminary design model 1080-938 with four P&W STJ1016 turbine bypass engines with MCTCB2 inlets and SS2D nozzles. The characteristics of both these aircraft are summarized in Table 3-2.

Table 3-2. Summary of HSCT aircraft characteristics used in the development of the Mach 2.0 and Mach 2.4 HSCT emission scenarios.

	Mach 2.4	Mach 2.0
Model Number	1080-924	1080-938
Engine	PW STJ989	PW STJ1016
Range (nautical miles)	5000	5000
Passengers	309	309
Design Payload (lbs)	64,890	64,890
Max. Takeoff Weight (lbs)	784,608	802,872
Wing Span (ft)	139	140
Wing Area (sq. ft.)	8180	8260

Model 1080-924



Configuration Description:

Maximum takeoff weight	784,600 pounds
Wing Area	8,180 square feet
Engine	STJ989
Payload	309 passengers, tri-class
Range	5,000 nmi - supersonic cruise

Figure 3-1. HSCT General Characteristics

The performance and emission characteristics for both Mach 2.0 and 2.4 were the same as those used as in the previous NASA contract work. (Baughcum, *et. al.*, 1994) However, it was found that the operating empty weights used in the previous emission scenario calculations had been incorrectly entered into the analysis data file and were not consistent with the performance data for the baseline model used in the study. This was corrected and revised emission inventories for Mach 2.0 and Mach 2.4 HSCTs on the 1993 AESA assessment network were calculated and delivered to NASA Langley. In this report, these revised 1993 AESA assessment scenarios are summarized and compared to the present universal airline results.

Emissions data for NOx, CO, and hydrocarbons were provided by GE/P&W for a generic HSCT combustor with a nominal NO_x emission index at supersonic cruise of approximately 5 gm NO_x (as NO_2)/kg fuel. Nitrogen oxides, carbon monoxide, and hydrocarbon emission levels were calculated from these data as a function of power setting and altitude. A similar calculation was completed to scale to a nominal cruise EI (NO_x)=15 scenario. For this scaling, the combustor was assumed to operate as a conventional combustor at low power settings and as an advanced low-NO_x combustor at higher settings. Based on discussions with both engine companies, the EI(NO_x) for this case was unchanged at low power settings and increased by a factor of 3 at higher thrust settings.

3.3 Mission Profiles

The mission profile procedures were described in detail in our previous NASA contractor report (Baughcum, *et. al.*, 1994). The basic HSCT mission profile was assumed as follows:

- 10 minute taxi-out
- all engine takeoff ground-roll and liftoff
- climbout to 1500 feet and accelerate
- climb to optimum cruise altitude (subsonic or supersonic, depending on whether over land or water)
- climbing supersonic cruise at constant Mach
- descent to 1500 feet
- approach and land
- 5 minute taxi-in

For a given HSCT model, fuel burned and emissions data were calculated for parametric mission cases: various takeoff weights (in increments of 50,000 pounds), two passenger-loading factors (100% and 65%), and with two cruise speeds (Mach 2.4 and Mach 0.9). These subsonic and supersonic mission profiles of varying range were used with a regression analysis to develop generalized performance for each HSCT mission segment as a function of weight. The details of this analysis were described in our previous NASA contractor report. (Baughcum, *et. al.*, 1994)

HSCT flight profiles of fuel burn and emissions were calculated from these performance and emissions data for each HSCT mission. These profiles combined with projected HSCT flight frequencies were then used to calculate the three-dimensional database, as described in our previous contractor report. (Baughcum, *et. al.*, 1994)

When calculating the flight profiles, all aircraft were assumed to fly according to design performance. For subsonic aircraft, cruise altitudes were calculated as a climbing cruise with the optimum altitude determined by the weight of the aircraft. For the HSCT, supersonic flight was allowed only over water and thus the mission profiles were more complicated than for subsonic aircraft.

Design optimum flight profiles between city-pairs were used to distribute emissions during takeoff, subsonic and supersonic climb and cruise, and descent. Based on these mission profiles, the calculated fuel burned and emissions were then transformed onto the database grid. Two missions, which are representative of the way in which an actual HSCT would be flown, are shown in Figures 3-2 and 3-3.

The simplest mission (Figure 3-2) is a flight almost exclusively over water, such as Seattle to Tokyo. The HSCT would take off and climb subsonically and then supersonically to a supersonic cruise altitude. It would then fly at supersonic cruise at the optimum altitude determined by its gross weight. As it approached Tokyo, it would descend and land. The cumulative fraction of the total NO_x emissions is plotted on the right axis. The plot illustrates that approximately 40% of the NO_x emissions would occur during takeoff, subsonic climb, and supersonic climb prior to supersonic cruise.

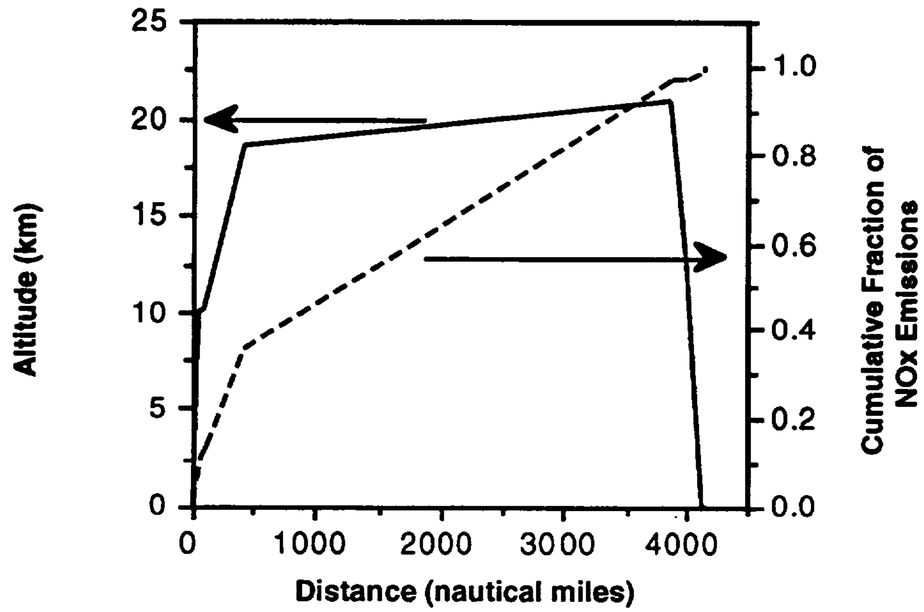


Figure 3-2. Mission profile for Mach 2.4 HSCT from Seattle to Tokyo.

A more complicated but still common mission is a flight in which one leg would be flown subsonically over land. This is illustrated in Figure 3-3 for a flight from Seattle to London. The HSCT would take off and climb to subsonic cruise altitudes. It would then cruise at subsonic speeds until it reached Hudson Bay where it would begin to climb supersonically. The HSCT would then cruise at supersonic speeds (altitude determined by the optimum performance) until descending near London. An even larger fraction (approximately 60%) of the NO_x emissions would occur during the subsonic climb, subsonic cruise, and supersonic climb prior to supersonic cruise.

A still more complicated mission, which was included in the calculations but not shown graphically, is a flight in which the aircraft might descend and climb several times to avoid flying supersonically over land. An example would be the Frankfurt to Bangkok route. In this case, the HSCT would fly subsonically over Europe, supersonically over the Mediterranean, subsonically over Arabia (stopping in Bahrain) supersonically over the Indian Ocean, and then subsonically inland over the Malay peninsula. Because of the high fuel consumption of supersonic climbs, such flight profiles were kept to a minimum in the scenario development.

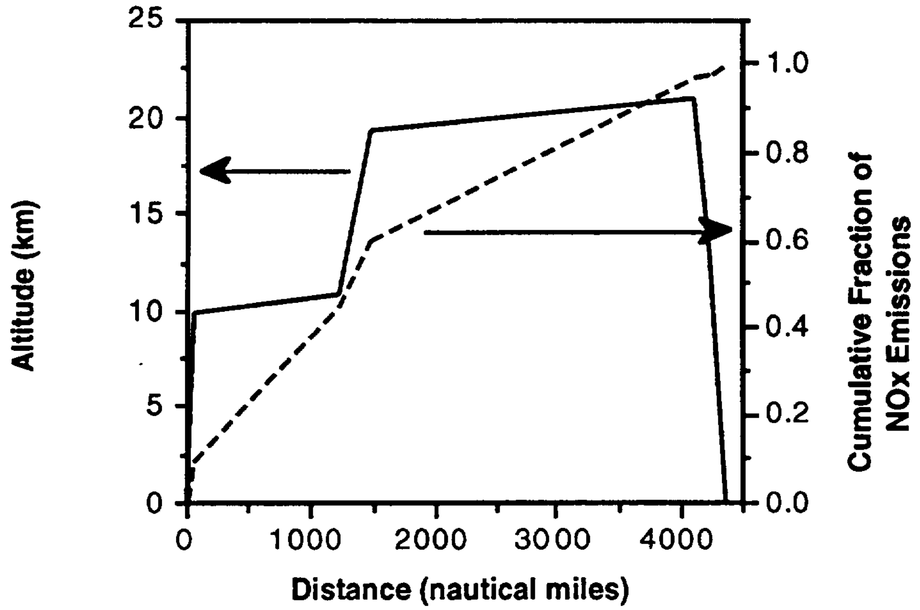


Figure 3-3. Mission profile for Mach 2.4 HSCT from Seattle to London.

3.4 Emission Calculation Procedures

All aircraft were assumed to fly according to design optimum performance. Altitudes and mission profiles were calculated based on the performance of the aircraft for its mission weight. Air traffic control constraints on routings were not considered. For each aircraft type considered, a separate three-dimensional data set of fuel burned and emissions was calculated. Subsonic aircraft were flown along great circle routes between cities. For the HSCT, routing between waypoints to avoid supersonic flight over land was used for many of the city-pairs. The HSCT was flown along great circle routes between these waypoints. For all flights, prevailing winds were not considered, based on the assumption that wind effects would largely be canceled out for round trips.

To calculate the global inventory of aircraft emissions, a computer model was developed which basically combines scheduling data (city pairs, departures, aircraft type) with aircraft performance and emissions data. The Global Atmospheric Emissions Code (GAEC) computer model was used to calculate fuel burned and emissions from files of airplane performance and engine emissions data. The aircraft performance file contains detailed performance input data for a wide range of operating conditions. Each engine emission input file contains emission indices tabulated as a function of the fuel flow rate. The GAEC model was described in more detail in the earlier report (Baughcum, *et. al.*, 1994).

For each route flown by the airplane/engine type, the takeoff gross weight required was calculated as a function of the city-pair route distance. The fuel burned was calculated for the following flight segments:

- Taxi-out
- Takeoff
- Climbout
- Subsonic Climb
- Subsonic Cruise
- Supersonic Climbout
- Supersonic Cruise
- Supersonic Descent
- Descent
- Approach and Land
- Taxi-in

For year 2015 subsonic aircraft, emissions of nitrogen oxides (NOx), hydrocarbons (HC) and carbon monoxide (CO) were projected from the ground level emission indices reported to the International Civil Aviation Organization (ICAO) for current aircraft. These measurements are reported at four thrust settings. The Boeing fuel flow correlation methodology was used to calculate emission indices for different flight phases, corrected for ambient temperature, pressure, and humidity. (Baughcum, *et. al.*, 1994; R. L. Martin, C. A. Oncina, and J. Zeeben, private communication). This methodology will be described in more detail in a future NASA contractor report describing the development of subsonic aircraft emission inventories for each month of 1992. (S. L. Baughcum, T. G. Tritz, and S. C. Henderson, private communication)

Subsonic aircraft emission inventories were calculated using the same technology improvements as reported in NASA CR-4592 (Baughcum, *et. al.*, 1994) except that a small error for the largest airplane type (P900) was discovered. The technology improvement factor for fuel flow given in Table 6-4 of NASA CR-4592 for the P900 aircraft had not been correctly used in the previous calculation. This was corrected so that the calculations are now consistent with the improvement factors shown in NASA CR-4592. As described later in this report, this makes only an approximately 2% change in the fuel use projected for the 2015 all subsonic fleet. Emission inventories for scheduled subsonic air traffic were calculated for the cases of fleets of 0, approximately 500, and approximately 1000 HSCTs on the universal airline network. Displacement of subsonic air traffic by HSCTs on individual routes was explicitly taken into account. The results are described in Sections 4 and 5 of this report.

Distributions of fuel usage and emissions were calculated for 1° latitude x 1° longitude x 1 km altitude cells. The altitudes used are pressure altitudes, not geometrical altitudes. The altitude corresponds to the geopotential altitudes of the U.S. Standard Atmosphere temperature and pressure profile and is thus pressure-gridded data. (U. S. Standard Atmosphere,1976) Commercial aircraft measure their altitudes using pressure altimeters. For each city-pair, the total route distance was calculated. The fuel burn rate and airplane gross weight were then calculated at discrete distances along the route path which corresponded to points where the airplane entered or left a cell (crossed any of the cells boundaries) or points where a transition in flight conditions occurred (climbout/climb, climb/cruise, cruise/descent, descent/approach and land, taxi-out/climbout, approach and land/taxi-in). The fuel burn rate would change dramatically at these transition points.

The emissions were calculated for each flight segment between the above described discrete points using the fuel burn rate within the segment. The total fuel burned in the segment was calculated as the difference in airplane gross weight at the segment end-points. The emissions were then assigned to a cell based on the coordinates of the endpoints.

4.0 Emission Inventory Results

A summary of the network statistics is shown in Table 4-1. An increase in the size of the HSCT fleet results in a greater number of city pairs included in the network. To satisfy the same passenger demand, a Mach 2.0 HSCT fleet requires about 6% more aircraft than needed for Mach 2.4 and flies at supersonic cruise about 4000 feet lower.

Doubling the size of the fleet results in an approximate doubling of the number of departures and an approximate doubling in the global fuel burn for the fleet. Comparison of the departure frequencies shown in Appendix C indicates that doubling the fleet size increases the flight frequencies on some routes but not on others, since it is sensitive to the market penetration analyses. Thus, changes in the geographical distribution of emissions may occur upon fleet growth. This will be discussed in more depth in Section 5.

The minimum altitudes shown in Table 4-1 correspond to the lowest altitudes at which supersonic cruise is reached. Because the Mach 2.4 HSCT must climb to higher altitudes which takes both time and distance, the Mach 2.0 is able to supersonically cruise on some segments for which the Mach 2.4 aircraft cannot.

Table 4-1. Summary of departure statistics for HSCT networks.

	1993 AESA Assessment Network (revised)	New Universal Network "500"	New Universal Network "1000"
Mach 2.4			
Number of Aircraft	500	499	991
Number of city pairs	193	243	392
Total daily departures	2,192	2,174	4,836
Total distance (miles/day)	7,458,802	7,728,939	14,632,996
Total Fuel (million lbs/day)	493.03	509.46	961.33
Maximum flight altitude (feet)	67,904	67,854	67,865
Minimum cruise altitude (feet)	57,722	57,547	57,547
Mach 2.0			
Number of Aircraft	532	528	1062
Number of city pairs	193	243	392
Total daily departures	2,192	2,174	4,836
Total distance (miles/day)	7,458,802	7,728,939	14,632,996
Total Fuel (million lbs/day)	504.79	524.27	979.92
Maximum flight altitude (feet)	63,956	63,907	63,920
Minimum cruise altitude (feet)	52,881	53,674	53,674

The fuel use and emissions for the different scenarios considered are summarized in Table 4-2 below. As shown below, the change from the simple ground rules to the market-driven universal airline network has only a small effect on the global fuel usage and NOx emissions for a fleet of 500 HSCTs. The biggest changes occurred in the geographical distribution of the emissions.

Table 4-2. Summary of fuel use and emissions for the different scenarios.

Mach Number	EI(NOx)	Number of HSCTs	Network	Fuel (kg/yr)	NOx (kg/yr)	HC (kg/yr)	CO (kg/yr)
Mach 2.4 fleet							
2.4	5	500	1993 AESA	8.16E+10	5.37E+08	2.99E+07	2.42E+08
2.4	5	499	universal	8.21E+10	5.35E+08	2.97E+07	2.41E+08
2.4	5	991	universal	1.57E+11	1.04E+09	5.88E+07	4.76E+08
2.4	15	500	1993 AESA	8.16E+10	1.46E+09	2.99E+07	2.42E+08
2.4	15	499	universal	8.21E+10	1.48E+09	2.97E+07	2.41E+08
2.4	15	991	universal	1.57E+11	2.82E+09	5.88E+07	4.76E+08
Mach 2.0 Fleet							
2.0	5	532	1993 AESA	8.36E+10	5.02E+08	2.89E+07	2.45E+08
2.0	5	528	universal	8.45E+10	5.04E+08	2.90E+07	2.47E+08
2.0	5	1062	universal	1.60E+11	9.65E+08	5.66E+07	4.78E+08
2.0	15	532	1993 AESA	8.36E+10	1.47E+09	2.89E+07	2.45E+08
2.0	15	528	universal	8.45E+10	1.48E+09	2.90E+07	2.47E+08
2.0	15	1062	universal	1.60E+11	2.82E+09	5.66E+07	4.78E+08
2015 Scheduled Subsonic Air Traffic							
Subsonic passenger aircraft (no HSCT fleet)				2.50E+11	2.32E+09	9.93E+07	1.11E+09
Subsonic passenger aircraft (with 500 M2.4 HSCTs)				2.22E+11	2.05E+09	9.34E+07	1.05E+09
Subsonic passenger aircraft (with 1000 M2.4 HSCTs)				1.97E+11	1.75E+09	1.95E+08	1.32E+09
2015 Cargo Aircraft				5.64E+09	4.91E+07	3.56E+06	2.77E+07

The fuel burned and emissions for the network used in the 1993 AESA assessment (Baughcum, *et. al.*, 1994) differ somewhat from those reported earlier . An error in the weight of the aircraft used in the performance calculations was discovered upon later analysis. Using the corrected weights, the emission inventories for the 1993 AESA assessment network were rerun. The total fleet fuel burn for the 500 aircraft fleet increased by about 7% from that reported earlier (Baughcum, *et. al.*, 1994) for the Mach 2.4 HSCT fleet. In addition, with the correct (heavier) weight, the supersonic cruise altitudes were slightly lower than those used in the earlier study. In the earlier report

(Baughcum, *et. al.*, 1994), the Mach 2.4 HSCT cruise altitudes were in the range of 59,639-69,098 feet. The corrections in the aircraft weight result in cruise altitudes about 1100 feet lower for the new scenarios. Similar problems were discovered and corrected for the Mach 2.0 emission inventories.

In this section, the results for the individual component inventories will be presented and discussed. In the next section, the overall results and changes between the different scenarios will be analyzed.

4.1 Mach 2.4 HSCT Fleet Results

Details of the results of HSCT fleet operations for different flight segments for the Mach 2.4 HSCT fleets are summarized in Tables 4-3 and 4-4. Table 4-5 shows the revised results for the 1993 AESA study. For all cases considered, the majority of the miles flown, fuel used and NOx emissions occur during supersonic cruise, where the actual EI at cruise is 5.42 (close to the nominal value of 5). The nominal EI=15 case was calculated by scaling the EI(NOx) at cruise by a factor of 3 as described in CR 4592 (Baughcum, *et. al.*, 1994). The calculated EI(NOx) at cruise for the nominal EI=15 case is 16.4 (see Appendix F).

The calculated fuel burned, emissions, and effective emission indices as a function of altitude (summed over latitude and longitude) for the Mach 2.4 HSCTs (both EI(NOx)=5 and 15) are tabulated in Appendix F. Also included in Appendix F are the revised results for the 1993 AESA assessment network.

Table 4-3. Daily mileage, fuel consumption, NOx emissions, and NOx emission index for the Mach 2.4 HSCT, nominal EI=5 flight segments. (Universal Network, 500 HSCTs)

Flight Segment	Daily Mileage (nmi)	Daily Fuel (1000 lbs)	Daily NOx (1000 lbs)	EI(NOx)
Taxi out	0	6,376	42	6.56
Initial Climb	96,929	40,780	353	8.65
Supersonic Climb	688,696	91,822	795	8.65
Supersonic Cruise	5,808,829	318,909	1,728	5.42
Supersonic Descent	264,008	1,714	11	6.56
Subsonic Cruise	555,250	34,864	289	8.30
Final Descent	315,230	12,559	82	6.56
Taxi in	0	2,435	16	6.56
Total	7,728,942	509,460	3,316	6.51

Table 4-4. Daily mileage, fuel consumption, NOx emissions, and NOx emission index for the Mach 2.4 HSCT, nominal EI=5 flight segments. (Universal Network, 1000 HSCTs)

Flight Segment	Daily Mileage	Daily Fuel (1000 lbs)	Daily NOx (1000 lbs)	EI(NOx)
Taxi out	0	14,184	93	6.56
Initial Climb	208,556	85,784	742	8.65
Supersonic Climb	1,369,248	180,857	1,565	8.65
Supersonic Cruise	10,415,248	561,414	3,041	5.42
Supersonic Descent	585,600	3,802	25	6.56
Subsonic Cruise	1,353,126	81,939	680	8.30
Final Descent	701,220	27,938	183	6.56
Taxi in	0	5,416	36	6.56
Total	14,632,998	961,333	6,365	6.62

Table 4-5. Daily mileage, fuel consumption, NOx emissions, and NOx emission index for the Mach 2.4 HSCT, nominal EI=5 flight segments. (1993 AESA assessment network(revised), 500 HSCTs)

Flight Segment	Daily Mileage	Daily Fuel (1000 lbs)	Daily NOx (1000 lbs)	EI(NOx)
Taxi out	0	6,429	42	6.56
Initial Climb	96,929	40,599	351	8.65
Supersonic Climb	666,449	88,815	769	8.65
Supersonic Cruise	5,380,866	295,890	1,603	5.42
Supersonic Descent	256,932	1,668	11	6.56
Supersonic Cruise & Descent	22,686	2,218	19	8.65
Subsonic Cruise	717,101	42,289	351	8.30
Final Descent	317,840	12,663	83	6.56
Taxi in	0	2,455	16	6.56
Total	7,458,803	493,027	3,245	6.58

The three-dimensional character of the emission inventories is illustrated in Figure 4-1, which shows the daily NOx emissions from a fleet of 500 Mach 2.4 (EI(NOx)=5) HSCTs on the universal airline network. The top panel shows NOx emissions as a function of altitude and latitude (summed over longitude). This represents the input to a 2-dimensional (altitude and latitude) stratospheric chemistry model, such as those used in the AESA assessment. Peak emissions occur at supersonic cruise at northern mid-latitudes. The bottom panel illustrates the route segments occurring at altitudes above 13 kilometers, which correspond to supersonic climb and cruise.

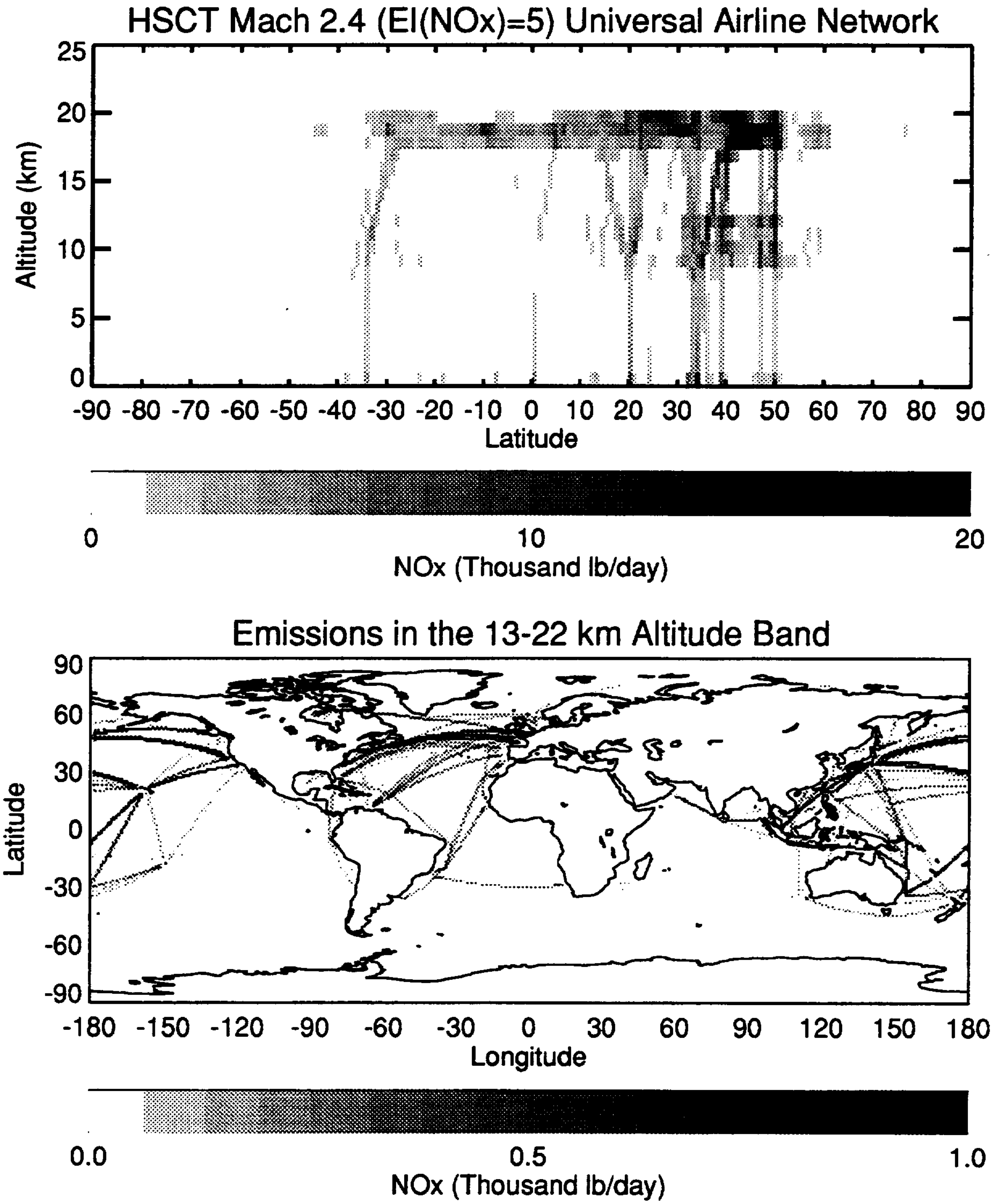


Figure 4-1. NOx emissions for a fleet of 500 Mach 2.4 HSCTs on the Universal Airline Network, as a function of altitude and latitude (summed over longitude, top panel) and as a function of latitude and longitude (summed over the 13-22 km altitude band, bottom panel). (Values greater than maximum are plotted as black.)

The fuel burned and emissions (NOx, hydrocarbons, and CO) as a function of altitude are shown in Figure 4-2 for fleets of 500 and 1000 Mach 2.4 HSCTs (EI(NOx)=5) on the present universal airline network. Not surprisingly, the larger fleet has approximately twice as much emissions and shows the same altitude distribution as the 500 HSCT fleet. Figure 4-3 shows the cumulative fraction of fuel burn and emissions plotted as a function of altitude for the two fleet sizes. The additional shorter routes for the 1000 HSCT fleet results in a larger fraction of the fuel burn and emissions occurring at lower altitudes for takeoff, climbout, and supersonic climb. Although the majority of the fuel use and NOx emissions will occur in the 18-21 kilometer altitude band, a significant fraction of the emissions occurs below 10 kilometers and between 10 and 18 kilometers.

The emission indices as a function of altitude are shown in Figure 4-4. The variation in emissions as a function of altitude reflect the changes in fuel burn rate at different stages of the flights and changes in power setting (with resulting changes in emission indices). Changes in HSCT fleet size have relatively little impact on the emission indices averaged over all missions.

The geographical distribution of the emissions for the universal airline network is displayed in Figure 4-5 for fleets of 500 and 1000 Mach 2.4 HSCTs. For these plots, the emissions for the entire fleet have been been summed over longitude and then plotted as a function of latitude. The plots show that most of the HSCT flights will occur at northern midlatitudes. Figure 4-6 shows the cumulative fraction as a function of latitude for each of the emissions, summing over the entire altitude range (0-22 km). For both fleet sizes, approximately 20% of the emissions occur in the Southern hemisphere, but the majority occur north of 30° North latitude.

The emissions injected above 13 kilometers in altitude, which will have the greatest impact on the stratospheric ozone layer, are shown in Figure 4-7 as a function of latitude for fleets of 500 and 1000 Mach 2.4 HSCTs. Figure 4-8 shows the cumulative fraction as a function of latitude for each of the emissions, summing over the 13 to 22 kilometer altitude band. Approximately 60% of the stratospheric NOx from the HSCT fleets will be injected north of 30° North latitude.

Growth of the fleet to 1000 active HSCTs causes only small changes in the geographical distribution. A more detailed discussion of the changes in emissions as the fleet grows from 500 to 1000 HSCTs will be presented in Section 5.

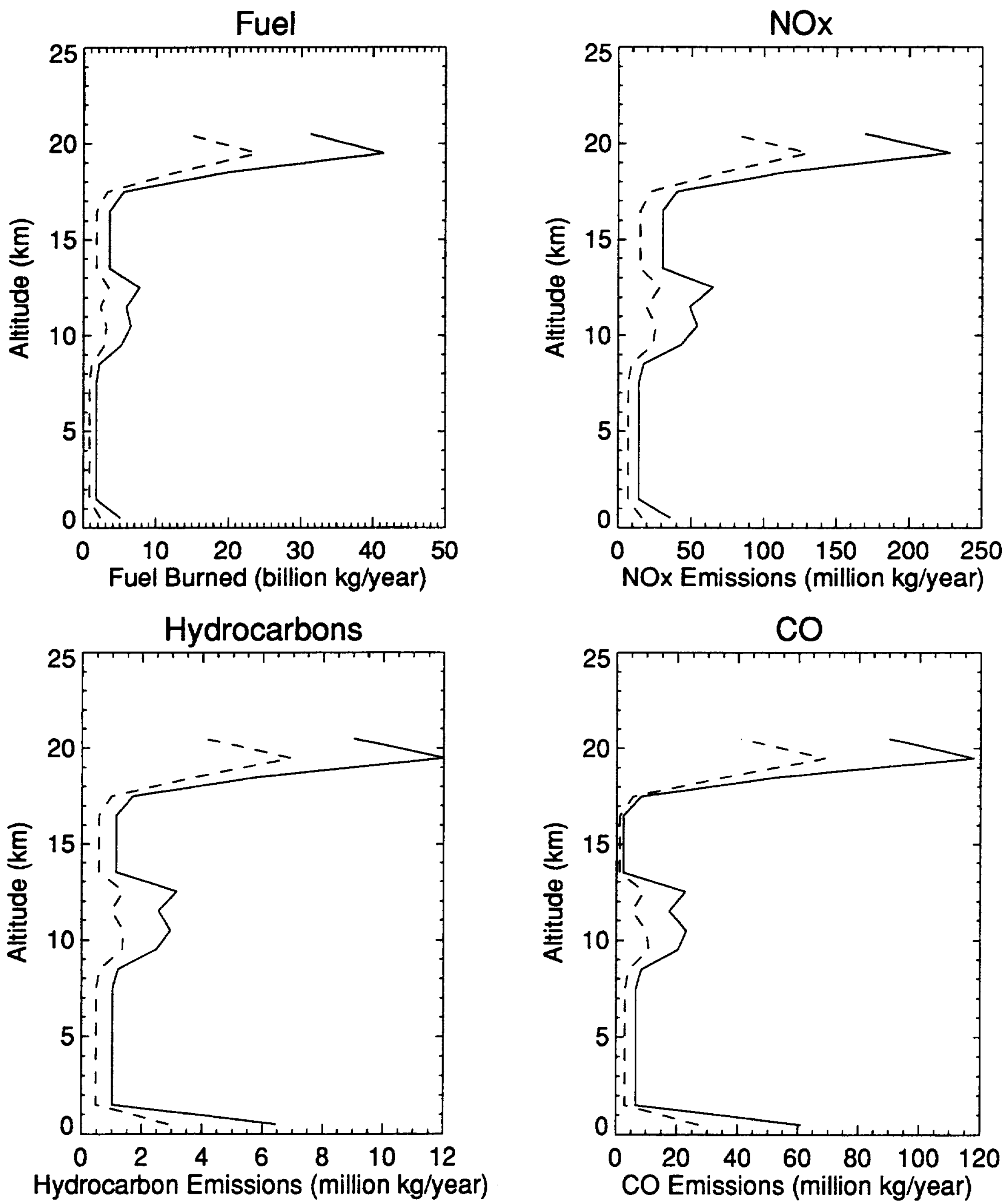


Figure 4-2. Fuel burned and emissions as a function of altitude for the universal airline HSCT network for a fleet of 500 (dashed line) and 1000 (solid line) Mach 2.4 HSCTs with EI(NOx) of approximately 5 at supersonic cruise (summed over latitude and longitude).

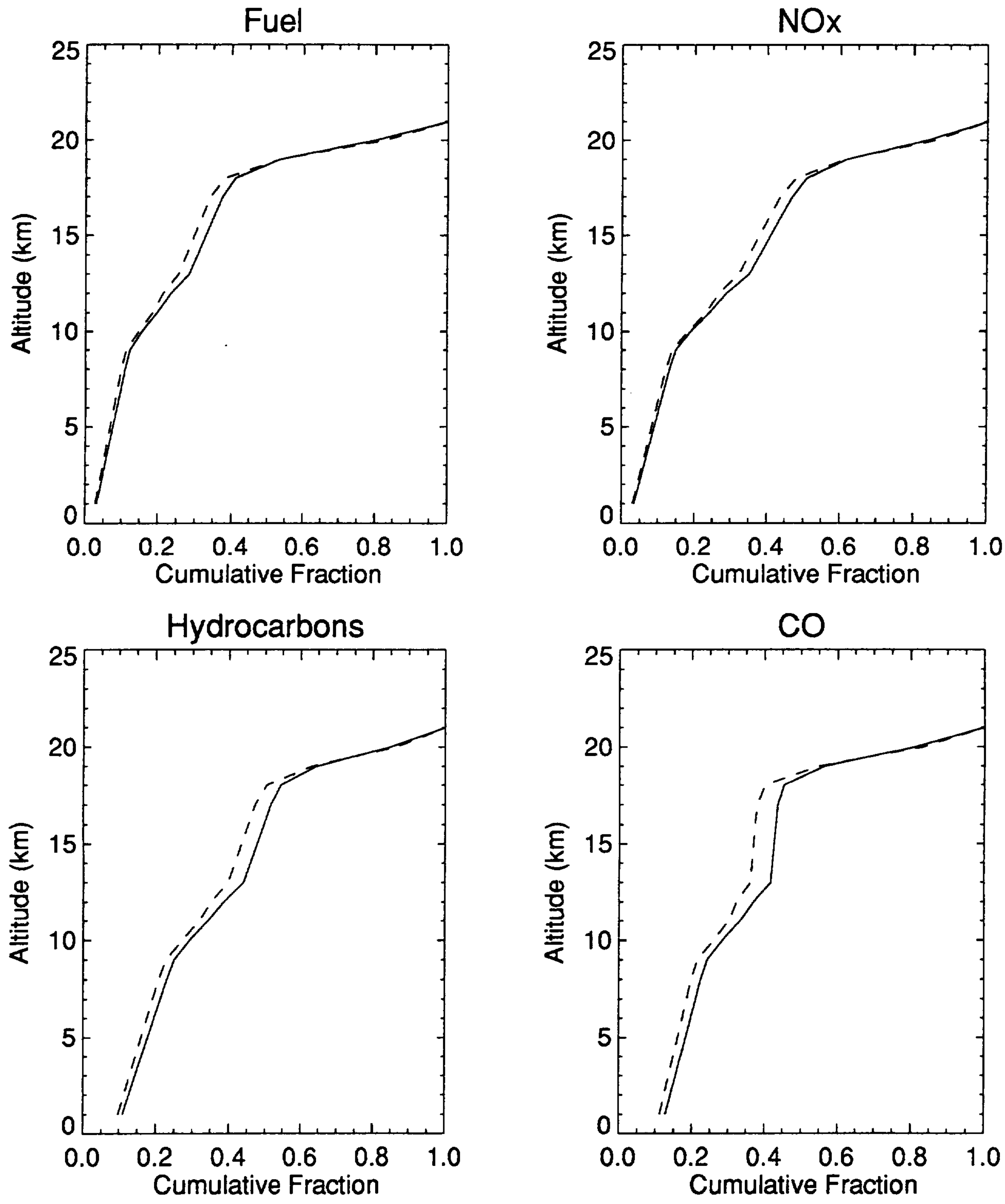


Figure 4-3. Cumulative fraction of fuel burned and emissions as a function of altitude for the universal airline HSCT network for a fleet of 500 (dashed line) and 1000 (solid line) Mach 2.4 HSCTs with EI(NOx) of approximately 5 at supersonic cruise (summed over latitude and longitude).

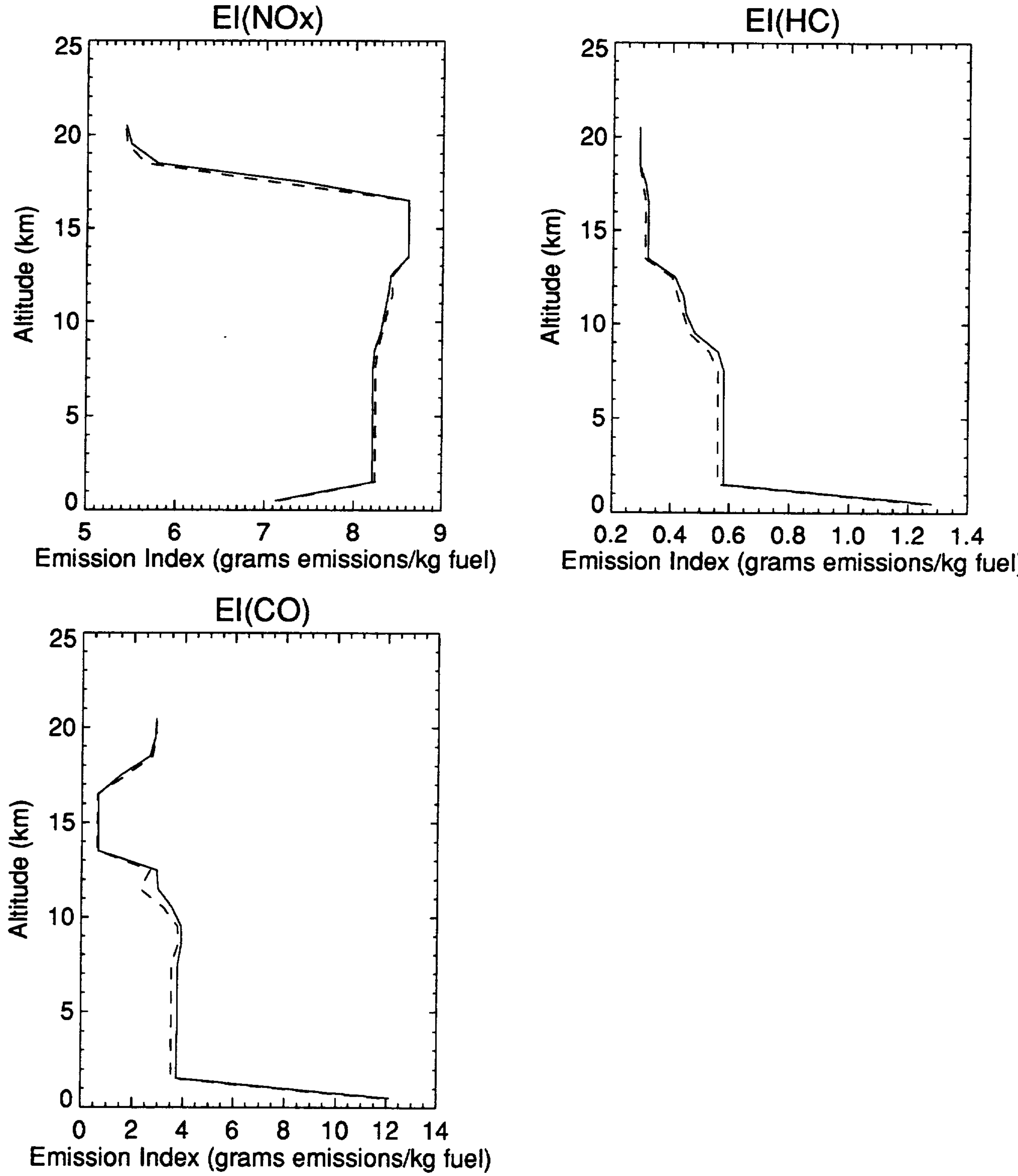


Figure 4-4. Emission indices as a function of altitude for the universal HSCT network for a fleet of 500 (dashed line) and 1000 (solid line) Mach 2.4 HSCTs with EI(NOx) of approximately 5 at supersonic cruise (summed over latitude and longitude).

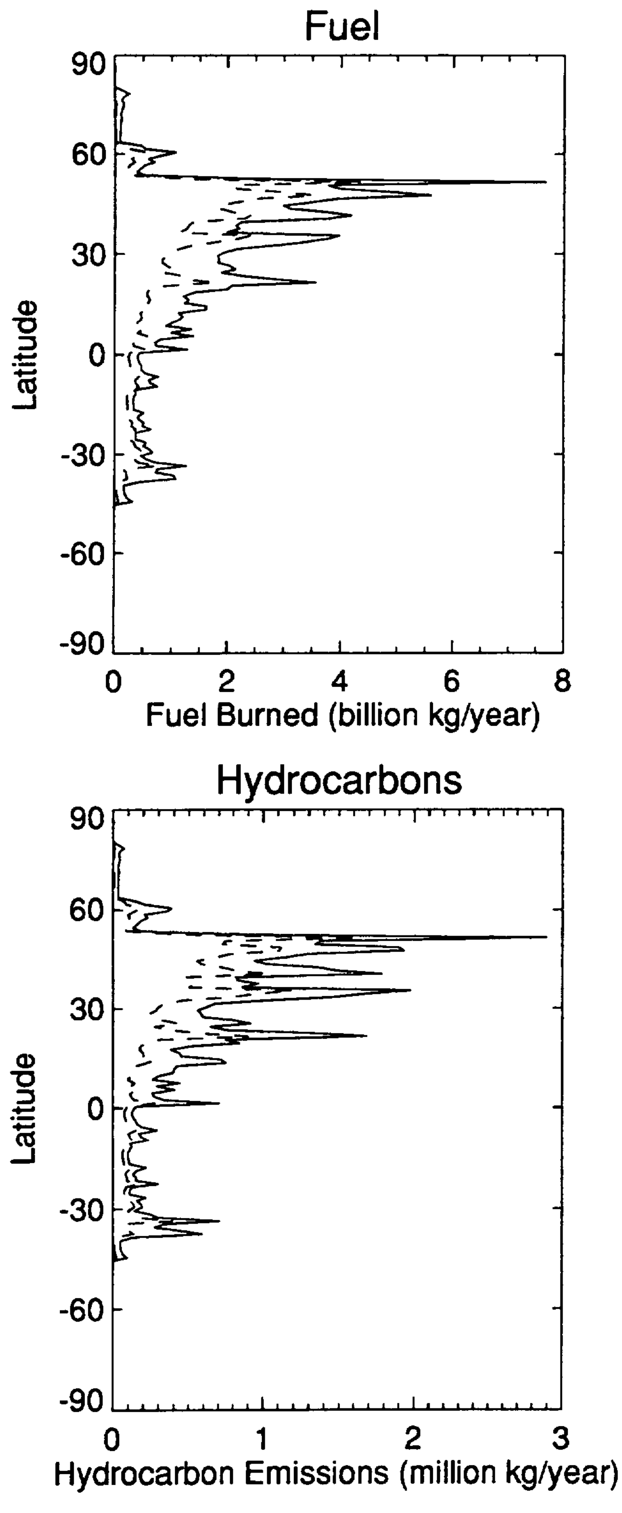


Figure 4-5. Fuel burned and emissions as a function of latitude for the universal airline HSCT network for fleets of 500 (dashed line) and 1000 (solid line) Mach 2.4 HSCTs with an EI(NOx) of approximately 5 at supersonic cruise (summed over altitude and longitude).

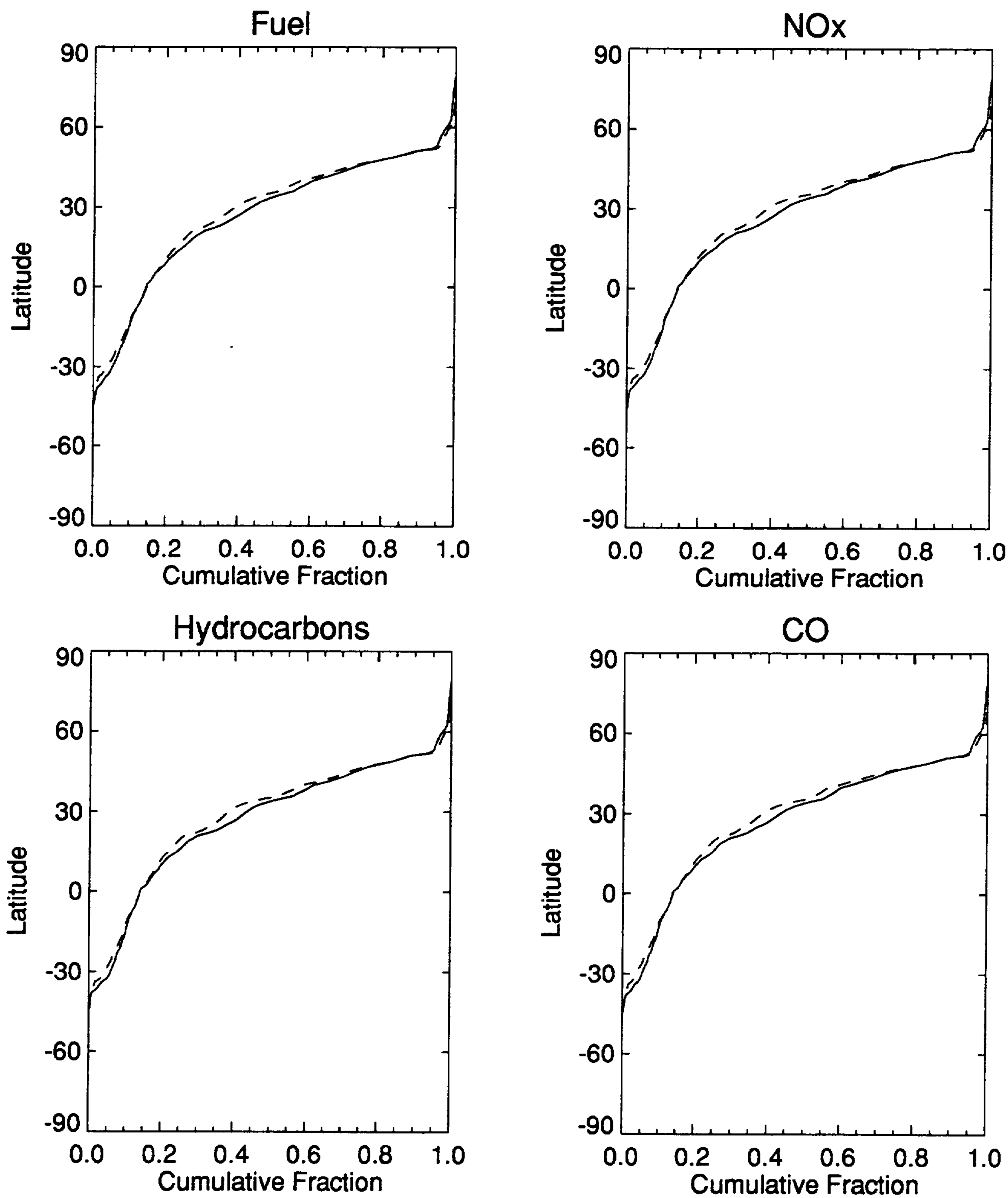


Figure 4-6. Cumulative fraction of fuel burned and emissions as a function of latitude for the universal airline HSCT network for fleets of 500 (dashed line) and 1000 (solid line) Mach 2.4 HSCTs with an EI(NOx) of approximately 5 at supersonic cruise (summed over altitude and longitude).

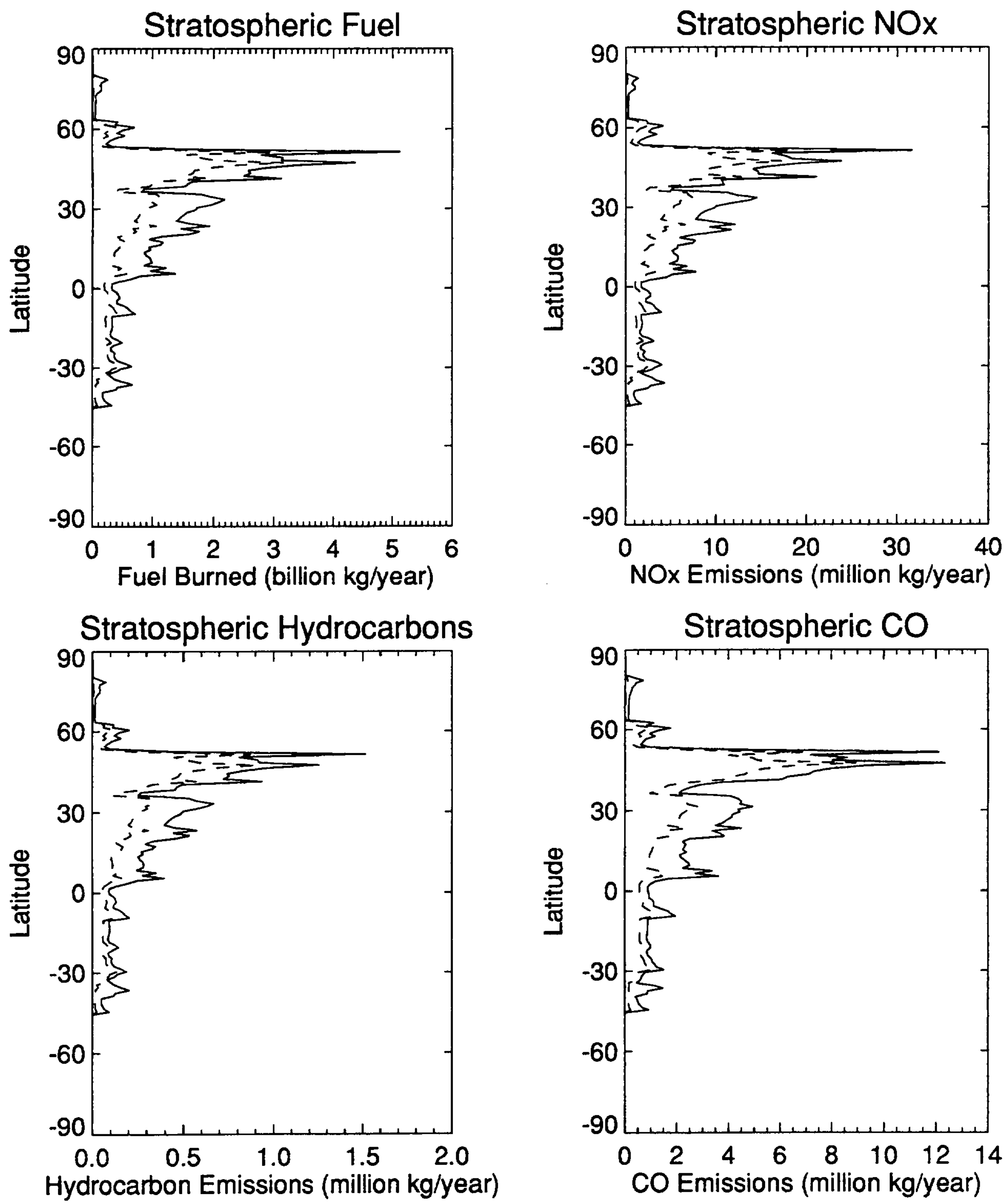


Figure 4-7. Fuel burned and emissions above 13 kilometers altitude as a function of latitude for the universal airline HSCT network for fleets of 500 (dashed line) and 1000 (solid line) Mach 2.4 HSCTs with an EI(NOx) of approximately 5 at supersonic cruise (summed over altitude and longitude).

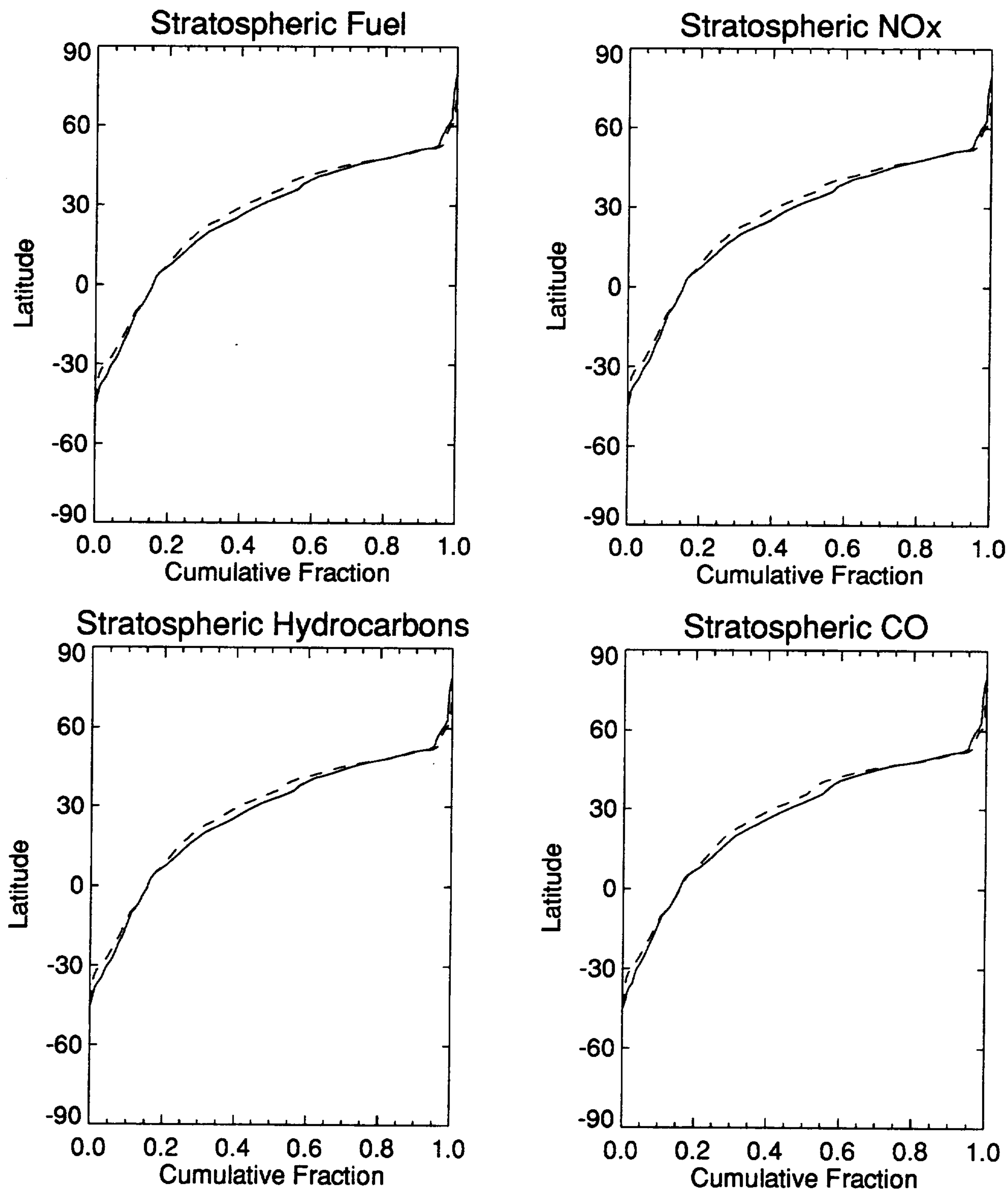


Figure 4-8. Cumulative fraction of fuel burned and emissions above 13 kilometers altitude as a function of latitude for the universal airline HSCT network for fleets of 500 (dashed line) and 1000 (solid line) Mach 2.4 HSCTs with an EI(NOx) of approximately 5 at supersonic cruise (summed over altitude and longitude).

4.2 Mach 2.0 HSCT fleet Results

Details of the results for different flight segments for the Mach 2.0 HSCT fleets are summarized in Tables 4-6 and 4-7. Table 4-8 shows the revised results for the 1993 AESA study. For all cases considered, the majority of the miles flown, fuel used and NOx emissions occur during supersonic cruise, where the calculated EI is 5.24.

The calculated fuel burned, emissions, and effective emission indices as a function of altitude (summed over latitude and longitude) for the M2.0 HSCTs (both EI(NOx)=5 and 15) are tabulated in Appendix G. Also included in Appendix G are the revised results for the 1993 AESA assessment network for Mach 2.0 HSCTs.

Since the same passenger demand was used for the Mach 2.0 fleet as was used for the Mach 2.4 fleet, the geographical distribution of emissions for the Mach 2.0 case is the same as for Mach 2.4. The altitude distributions are similar except that the supersonic cruise emissions occur approximately 4000 feet lower.

Table 4-6. Daily mileage, fuel consumption, NOx emissions, and NOx emission index for the Mach 2.0 HSCT, nominal EI=5 flight segments. (Universal Network, passenger demand corresponding to 500 Mach 2.4 HSCTs)

Flight Segment	Daily Mileage (nmi)	Daily Fuel (1000 lbs)	Daily NOx (1000 lbs)	EI(NOx)
Taxi out	0	5,752	40	7.00
Initial Climb	87,860	36,689	297	8.10
Supersonic Climb	482,933	66,765	541	8.10
Supersonic Cruise	6,079,332	367,116	1,925	5.24
Supersonic Descent	197,106	1,375	10	6.99
Subsonic Cruise	562,131	32,536	214	6.57
Final Descent	319,578	11,818	83	6.99
Taxi in	0	2,222	16	6.99
Total	7,728,940	524,273	3,125	5.96

Table 4-7. Daily mileage, fuel consumption, NOx emissions, and NOx emission index for the Mach 2.0 HSCT, nominal EI=5 flight segments. (Universal Network, passenger demand corresponding to 1000 Mach 2.4 HSCTs)

Flight Segment	Daily Mileage (nmi)	Daily Fuel (1000 lbs)	Daily NOx (1000 lbs)	EI(NOx)
Taxi out	0	12,796	90	7.00
Initial Climb	188,134	76,870	623	8.10
Supersonic Climb	965,212	131,653	1,067	8.10
Supersonic Cruise	10,963,144	648,318	3,400	5.24
Supersonic Descent	437,346	3,052	21	6.99
Subsonic Cruise	1,368,262	76,000	499	6.57
Final Descent	710,892	26,288	184	6.99
Taxi in	0	4,942	35	6.99
Total	14,632,990	979,919	5,918	6.04

Table 4-8. Daily mileage, fuel consumption, NOx emissions, and NOx emission index for the Mach 2.0 HSCT, nominal EI=5 flight segments. (1993 AESA assessment network (revised), passenger demand corresponding to 500 Mach 2.4 HSCTs)

Flight Segment	Daily Mileage (nmi)	Daily Fuel (1000 lbs)	Daily NOx (1000 lbs)	EI(NOx)
Taxi out	0	5,800	41	7.00
Initial Climb	87,777	36,453	295	8.10
Supersonic Climb	472,821	65,351	529	8.10
Supersonic Cruise	5,649,821	341,743	1,792	5.24
Supersonic Descent	194,285	1,356	9	6.99
Supersonic Cruise & Descent	11,777	1,146	9	8.10
Subsonic Cruise	720,099	38,788	255	6.57
Final Descent	322,224	11,916	83	6.99
Taxi in	0	2,240	16	6.99
Total	7,458,804	504,792	3,030	6.00

Since the Mach 2.0 and Mach 2.4 HSCT fleets are flown on the same passenger demand network in this study, the primary difference between the two fleets is that the Mach 2.0 fleet requires about 6% more aircraft to satisfy the same passenger demand and the aircraft cruise supersonically about 4000 feet lower. Tables of the emissions as a function of altitude for Mach 2.0 are included as Appendix G.

4.3 Year 2015 Subsonic Fleet Results

For year 2015 subsonic passenger aircraft, 10 jet categories and one generic turboprop were considered. These are summarized in Table 4-9. These are the same categories as used in our previous study (Baughcum, *et. al.*, 1994). Aircraft performance and emissions characteristics were the same as used in the previous study except that an error in the performance data used for the P900 aircraft type (> 900 passengers) was corrected, as described in Section 3. This increased the total projected fuel burn for the all subsonic 2015 scheduled passenger fleet by about 2%.

Results are presented here for the the subsonic passenger fleet in use for the cases where there are 0, 500, and 1000 Mach 2.4 HSCTs in use on the universal network. Subsonic cargo aircraft data was not updated from that presented earlier (Baughcum, *et. al.*, 1994) but is included in the summaries.

Table 4-9. Classes of "Generic" Subsonic Passenger Aircraft Used in the 2015 Scenario Construction

Class	Seating Capacity	Average Seats
TBP (turboprop)	0 - 49	30
P060	50 - 69	60
P080	70 - 109	85
P120	110 - 139	120
P180	140 - 199	170
P250	200 - 299	250
P350	300 - 399	350
P500	400 - 599	500
P700	600 - 799	700
P900	> 800	900

The results for the three subsonic passenger fleets are summarized by aircraft type in Tables 4-10, 4-11, and 4-12. Fuel use by subsonic passenger jets was projected to drop by approximately 11% because of the displacement caused by 500 HSCTs in operation and 21% in the presence of 1000 HSCTs. As discussed in Section 5, total fuel usage for the combined fleet of subsonic and HSCT fleets would increase as HSCTs displace subsonic aircraft.

The calculated fuel burn, emissions, and effective emission indices as a function of altitude (summed over latitude and longitude) for the year 2015 subsonic passenger fleets are tabulated in Appendix G.

Table 4-10 Globally Computed Fuel Burned, Emissions, and Emission Indices by Aircraft Type for 2015 Scheduled Subsonic Airliners if 500 Mach 2.4 HSCTs are in operation on the universal network.

					Globally Averaged Emission Indices		
File	**Fuel (kg/yr)**	**NO_x (kg/yr)**	**HC (kg/yr)**	**CO (kg/yr)**	**EI (NO_x)**	**EI (HC)**	**EI (CO)**
P060	2.63E+09	1.49E+07	1.47E+06	1.44E+07	5.66	0.56	5.50
P080	8.67E+09	6.84E+07	2.91E+06	6.59E+07	7.88	0.34	7.60
P120	1.42E+10	1.04E+08	8.02E+06	1.25E+08	7.37	0.57	8.85
P180	2.34E+10	1.73E+08	5.80E+06	1.23E+08	7.39	0.25	5.26
P250A	2.49E+10	2.15E+08	1.64E+07	1.63E+08	8.64	0.66	6.56
P250B	1.65E+10	1.21E+08	1.16E+07	6.23E+07	7.33	0.70	3.77
P350	4.09E+10	4.29E+08	1.48E+07	1.56E+08	10.50	0.36	3.82
P500	5.07E+10	4.74E+08	1.80E+07	2.15E+08	9.33	0.35	4.25
P700	2.24E+10	2.61E+08	4.18E+06	5.46E+07	11.66	0.19	2.44
P900	1.37E+10	1.45E+08	3.02E+06	4.22E+07	10.59	0.22	3.07
TBP	4.13E+09	4.40E+07	7.29E+06	2.41E+07	10.65	1.76	5.83
Total	2.22E+11	2.05E+09	9.34E+07	1.05E+09	9.23	0.42	4.71

Table 4-11 Globally computed fuel burned, emissions, and emission Indices by Aircraft Type for 2015 Scheduled Subsonic Airliners if 1000 Mach 2.4 HSCTs are in operation on the universal network.

					Globally Averaged Emission Indices		
File	**Fuel (kg/yr)**	**NO_x (kg/yr)**	**HC (kg/yr)**	**CO (kg/yr)**	**EI (NO_x)**	**EI (HC)**	**EI (CO)**
P060	2.63E+09	1.49E+07	1.47E+06	1.44E+07	5.66	0.56	5.50
P080	8.67E+09	6.84E+07	2.91E+06	6.59E+07	7.88	0.34	7.60
P120	1.41E+10	1.04E+08	8.01E+06	1.25E+08	7.37	0.57	8.86
P180	2.34E+10	1.73E+08	5.81E+06	1.23E+08	7.39	0.25	5.26
P250A	2.46E+10	2.13E+08	1.63E+07	1.62E+08	8.65	0.66	6.58
P250B	1.31E+10	9.59E+07	9.54E+06	5.11E+07	7.32	0.73	3.90
P350	3.65E+10	3.85E+08	1.38E+07	1.45E+08	10.56	0.38	3.97
P500	4.79E+10	4.49E+08	1.69E+07	2.02E+08	9.36	0.35	4.22
P700	1.64E+10	1.95E+08	3.61E+06	4.60E+07	11.92	0.22	2.80
P900	5.41E+09	6.10E+07	1.42E+06	1.91E+07	11.28	0.26	3.53
TBP	4.13E+09	4.40E+07	7.29E+06	2.41E+07	10.65	1.76	5.83
Total	1.97E+11	1.80E+09	8.71E+07	9.78E+08	9.16	0.44	4.97

Table 4-12 Globally Computed Fuel Burned, Emissions, and Emission Indices by Aircraft Type for 2015 Scheduled Subsonic Airliners if no HSCT Fleet Exists (revised from NASA CR 4592)

File	Fuel (kg/yr)	NO_x (kg/yr)	HC (kg/yr)	CO (kg/yr)	Globally Averaged Emission Indices EI (NO_x)	EI (HC)	EI (CO)
P060	2.63E+09	1.49E+07	1.47E+06	1.44E+07	5.66	0.56	5.50
P080	8.67E+09	6.84E+07	2.91E+06	6.59E+07	7.88	0.34	7.60
P120	1.42E+10	1.04E+08	8.02E+06	1.25E+08	7.37	0.57	8.85
P180	2.35E+10	1.73E+08	5.81E+06	1.23E+08	7.39	0.25	5.25
P250A	2.49E+10	2.15E+08	1.64E+07	1.63E+08	8.64	0.66	6.56
P250B	2.10E+10	1.54E+08	1.39E+07	7.59E+07	7.33	0.66	3.61
P350	4.31E+10	4.51E+08	1.52E+07	1.61E+08	10.48	0.35	3.74
P500	5.25E+10	4.88E+08	1.86E+07	2.23E+08	9.31	0.35	4.26
P700	3.15E+10	3.61E+08	5.11E+06	6.84E+07	11.48	0.16	2.17
P900	2.40E+10	2.46E+08	4.63E+06	6.66E+07	10.22	0.19	2.77
TBP	4.13E+09	4.40E+07	7.29E+06	2.41E+07	10.65	1.76	5.83
Total	2.50E+11	2.32E+09	9.94E+07	1.11E+09	9.28	0.40	4.44

5.0 Analysis and Discussion

5.1 Comparison of HSCT Universal Fleet Emissions with Old Network Results

The weight corrections discussed earlier resulted in an increase in global fuel use of 7% by the HSCT fleet and cruise altitudes about 1100 feet lower than those described earlier ((Baughcum, *et. al.*, 1994) and used in the 1993 AESA assessment. Changing from the 1993 AESA assessment network to the new universal airline network for the same number of active HSCTs in-service has little effect (less than 1%) on the global fuel burn or emissions for the HSCT fleet, when the correct OEW is used, as shown in Table 5-1.

Table 5-1. Comparison of the new universal network fuel use and emissions with the revised 1993 AESA assessment network results.

Mach 2.4 HSCT EI(NOx)=5	Fuel (kg/year)	NOx (kg/year)	HC (kg/year)	CO (kg/year)
1993 AESA assessment network (500 HSCTs) (Baughcum, *et. al.*, 1994)	7.64E+10	5.00E+08	2.83E+07	2.33E+08
1993 AESA assessment network (500 HSCTs)(revised)	8.16E+10	5.37E+08	2.99E+07	2.42E+08
new universal network (500 HSCTs)	8.21E+10	5.35E+08	2.97E+07	2.41E+08
difference relative to the 1993 AESA network (revised)	5.02E+08	-2.63E+06	-2.09E+05	-1.15E+06
Percent change	0.61%	-0.49%	-0.70%	-0.47%

The change in ground rules has a much larger effect on the geographical distribution of the emissions. This is shown in Figure 5-1 where the 3-dimensional inventory of emissions calculated for the universal airline network is compared with the 1993 AESA assessment network (revised to account for the correct OEW). The top panel shows the increases in NOx emissions as a function of latitude and altitude when the universal airline network is compared with the 1993 AESA assessment network results (revised). The bottom panel shows the decreases in NOx emissions when the universal airline network is compared with the 1993 AESA assessment network results (revised). In general, the new universal airline network has the HSCT flying at subsonic cruise less than in the 1993 AESA assessment network. There are also fewer emissions at high northern latitudes and more in the Southern hemisphere for the new network.

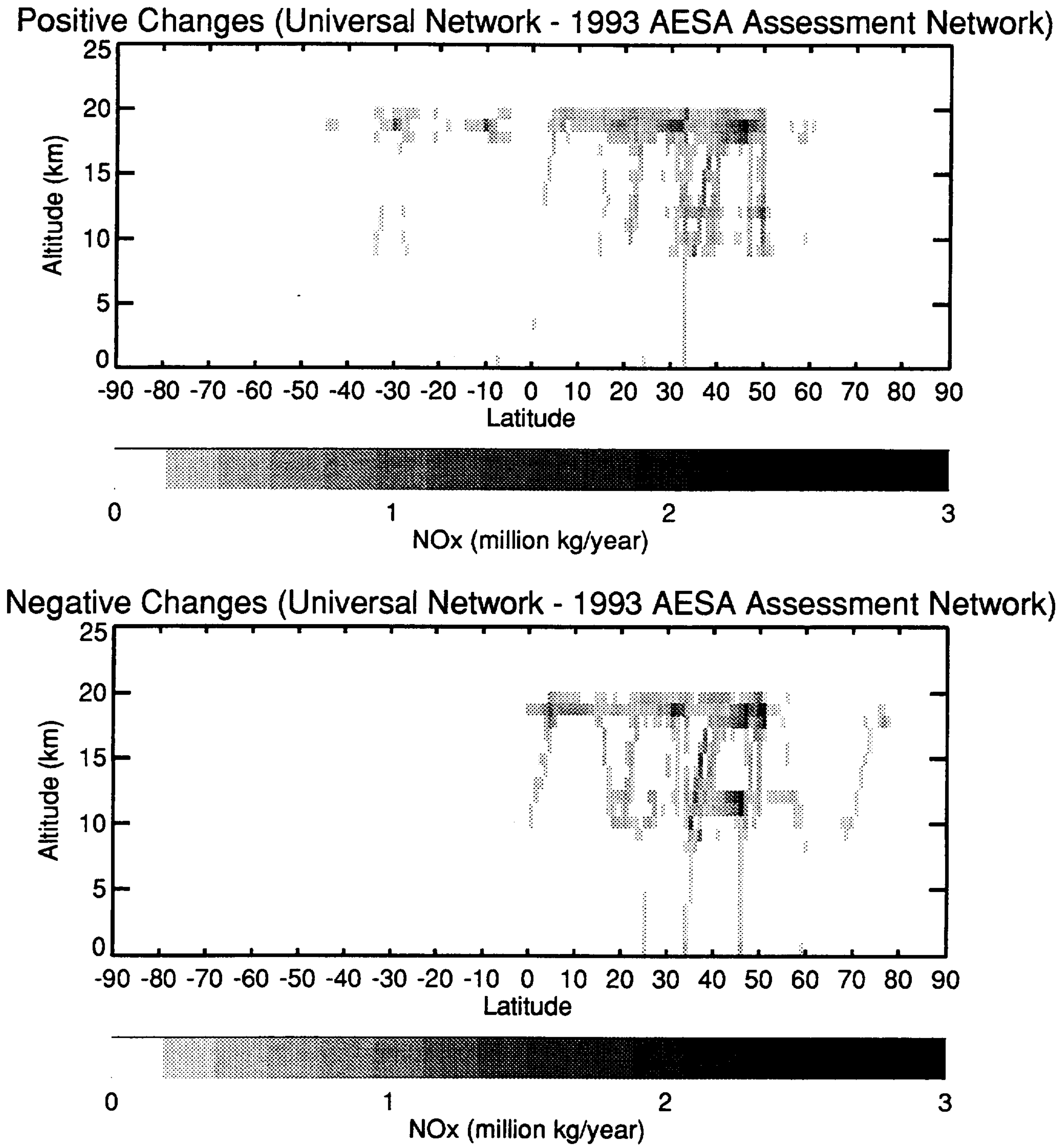


Figure 5-1. Comparison of NOx emissions from the universal airline network with the revised 1993 AESA assessment network for 500 Mach 2.4 [EI(NOx)=5] HSCTs. The top panel shows positive changes, while the bottom panel shows negative changes. (summed over longitude)

Since the changes in the high altitude emissions are expected to have the largest effects on ozone impact, the discussion will focus on changes in stratospheric NOx emissions. Figure 5-2 shows a comparison of the NOx emissions above 13 kilometers altitude for the 1993 AESA assessment network (revised) and the new 500 HSCT universal airline network. High altitude NOx emissions are greater in the southern hemisphere for each of the 10 degree latitude bands shown here. NOx emissions at extremely high northern latitudes (>70N) are less than with the old network. The analysis shows a net increase in the tropics of high altitude NOx emissions compared with the old network. At northern mid-latitudes the results are approximately the same.

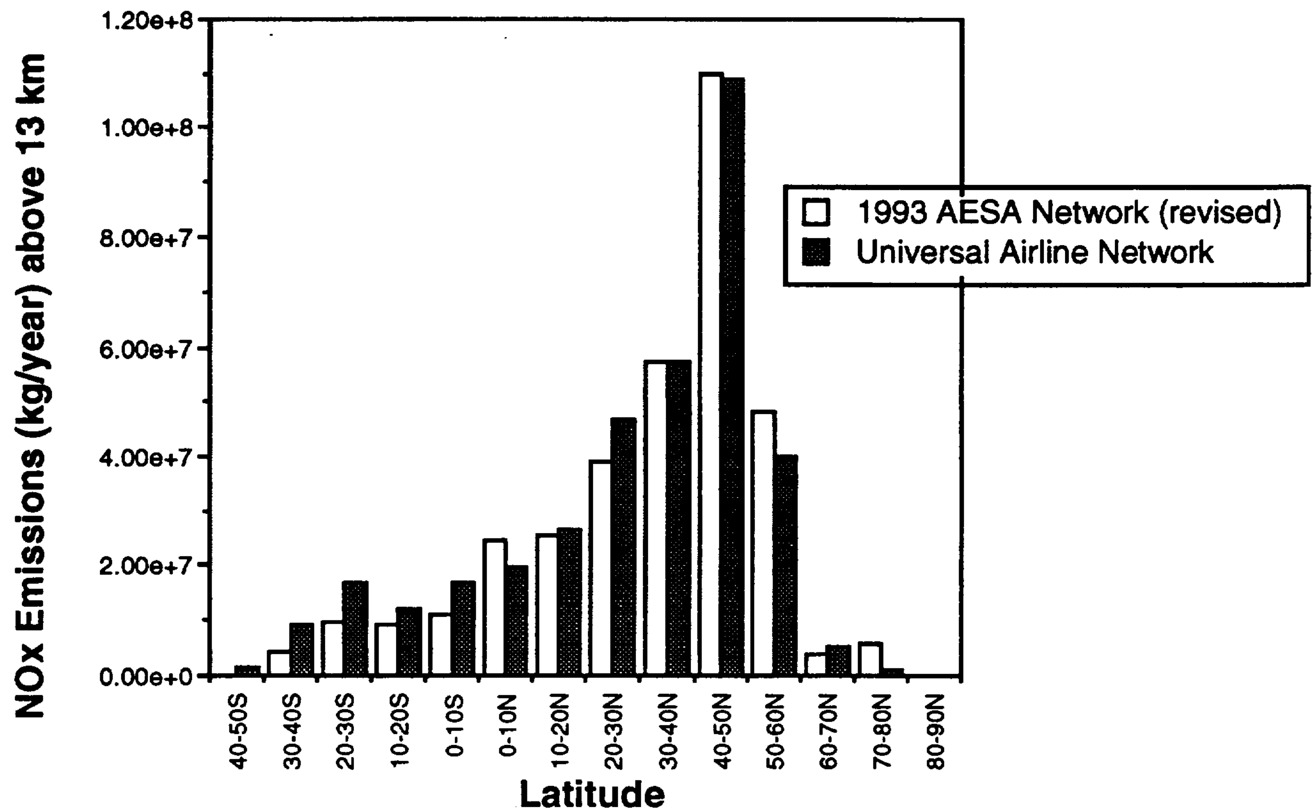


Figure 5-2. NOx emissions above 13 kilometers as a function of latitude, comparing the new universal airline scenario with the 1993 AESA assessment network scenario (revised) for 500 Mach 2.4 HSCTs.

Figure 5-3 shows the differences in fuel burned and NOx emissions at high resolution (1 degree latitude) as a function of latitude (summed over longitude). For these cases, the results are shown summed over all altitudes (the two top figures) and summed over altitudes above 13 km (bottom two figures). The high resolution plots illustrate that although there are systematic differences between the two networks in some latitude bands (e.g., the

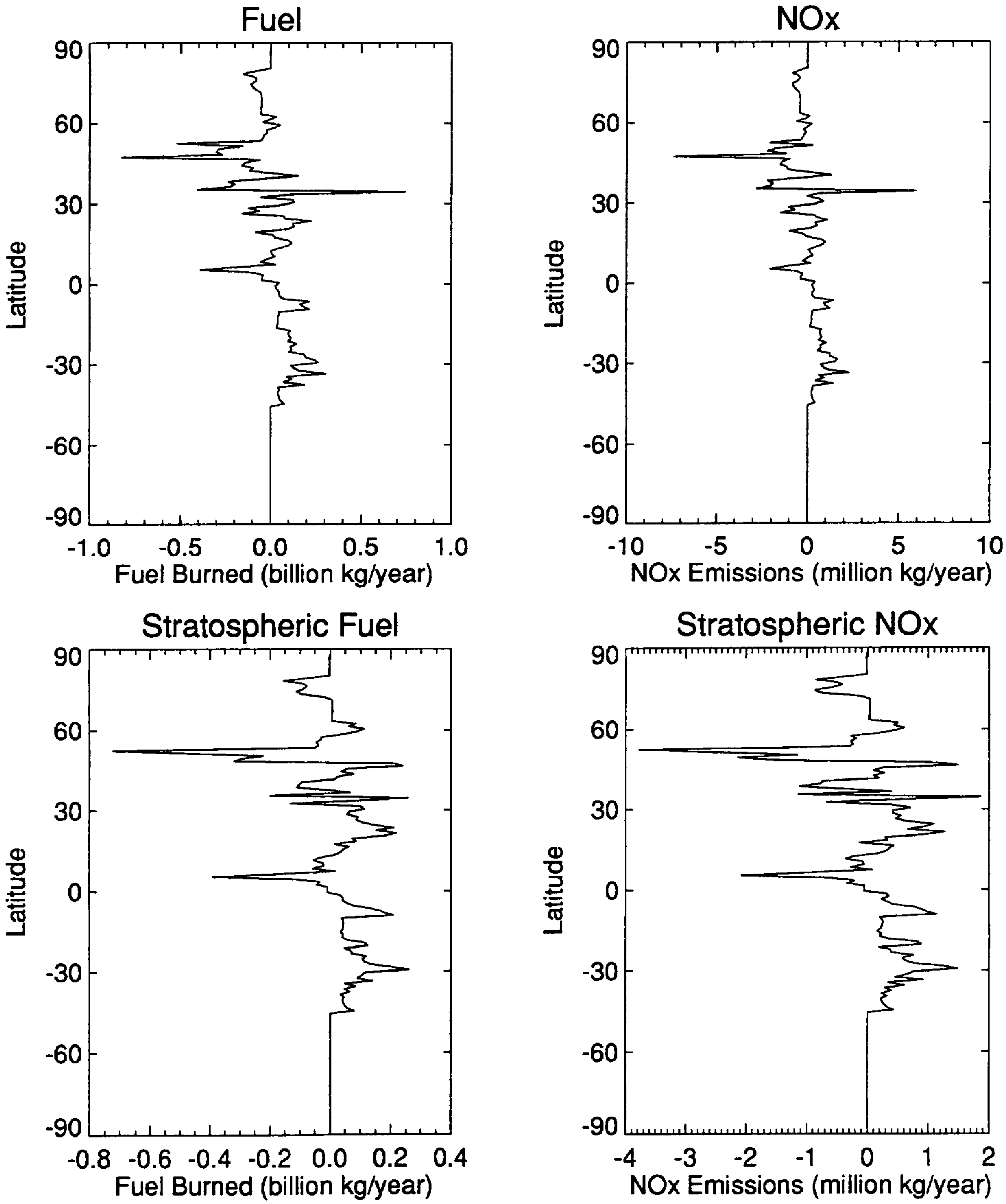


Figure 5-3. Differences in fuel burn and emissions between the new universal HSCT network and the 1993 AESA assessment network (revised) for a fleet of 500 Mach 2.4 HSCTs with EI(NOx) at cruise of approximately 5, plotted as a function of latitude. Stratospheric emissions here refer to emissions above 13 km.

Southern hemisphere), in other bands the differences are much more complicated (e.g., 30-40 North latitude).

Figure 5-4 shows the cumulative fraction of NOx emissions above 13 kilometers, emphasizing that in the new network about 15% of the stratospheric NOx emissions will occur in the southern hemisphere, compared to 10% for the old network. Most of the changes are an increase in stratospheric cruise occurring in the tropics. Since 2-D modeling calculations have indicated that HSCT emissions in the tropics may have greater impact on stratospheric ozone than for similar injections at mid-latitudes, these changes are worth noting for the AESA assessment calculations.

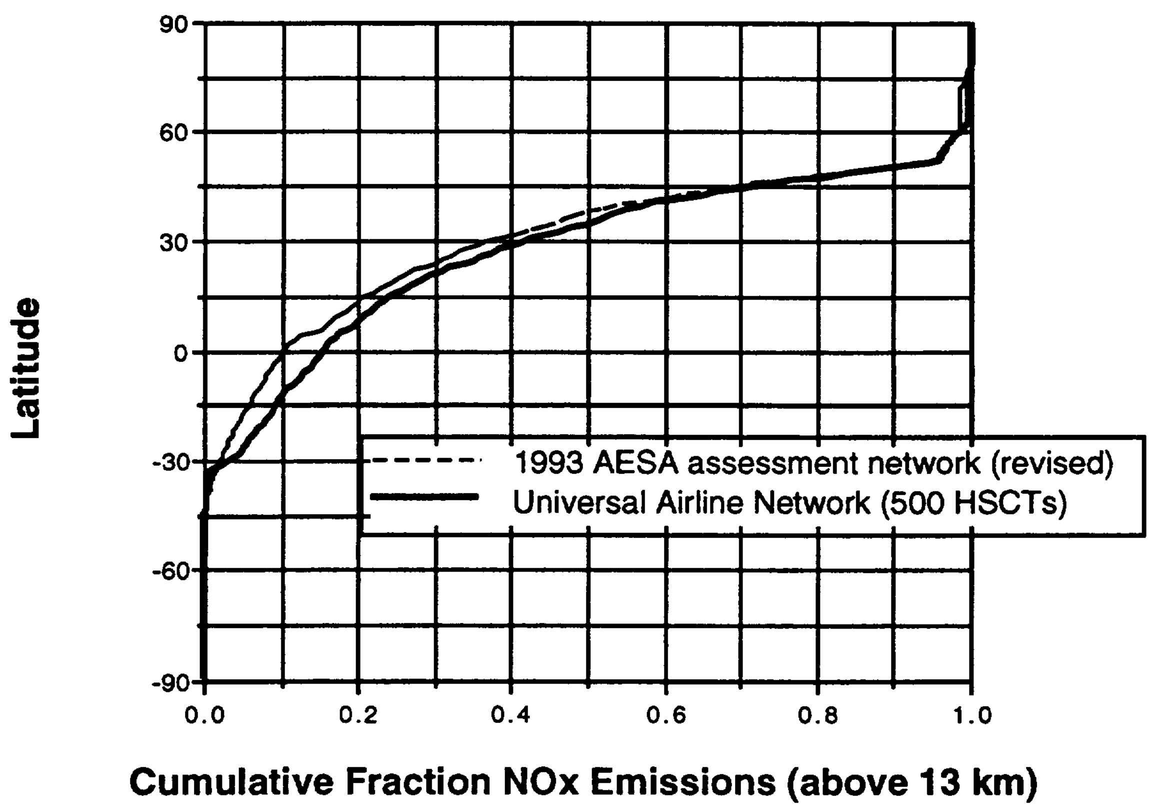


Figure 5-4. Cumulative fraction of NOx emissions above 13 km plotted as a function of latitude, comparing the results for the universal airline network with the revised 1993 AESA assessment network for the Mach 2.4 HSCT (EI(NOx)=5)).

5.2 Fleet Growth Effects

The effect of doubling the HSCT fleet from 500 to 1000 HSCTs on the universal airline network is summarized in Table 5-2. The global fuel use and emissions are projected to almost double with the fleet size.

Table 5-2. Comparison of the fuel use and emissions between the 500 and 1000 aircraft HSCT fleets.

Mach 2.4 HSCT EI(NOx)=5	Fuel (kg/year)	NOx (kg/year)	HC (kg/year)	CO (kg/year)
universal network (500 HSCTs)	8.21E+10	5.35E+08	2.97E+07	2.41E+08
universal network (1000 HSCTs)	1.57E+11	1.04E+09	5.88E+07	4.76E+08
difference (1000- 2 x 500)	-7.52E+09	-3.11E+07	-5.25E+05	-7.09E+06
% difference (1000-2 x 500)	-4.58%	-2.91%	-0.88%	-1.47%

If we compare the NOx emissions injected at altitudes above 13 kilometers (Figure 5-5), it is clear that emissions in some latitude bands increase at different rates as the HSCT fleet is doubled.

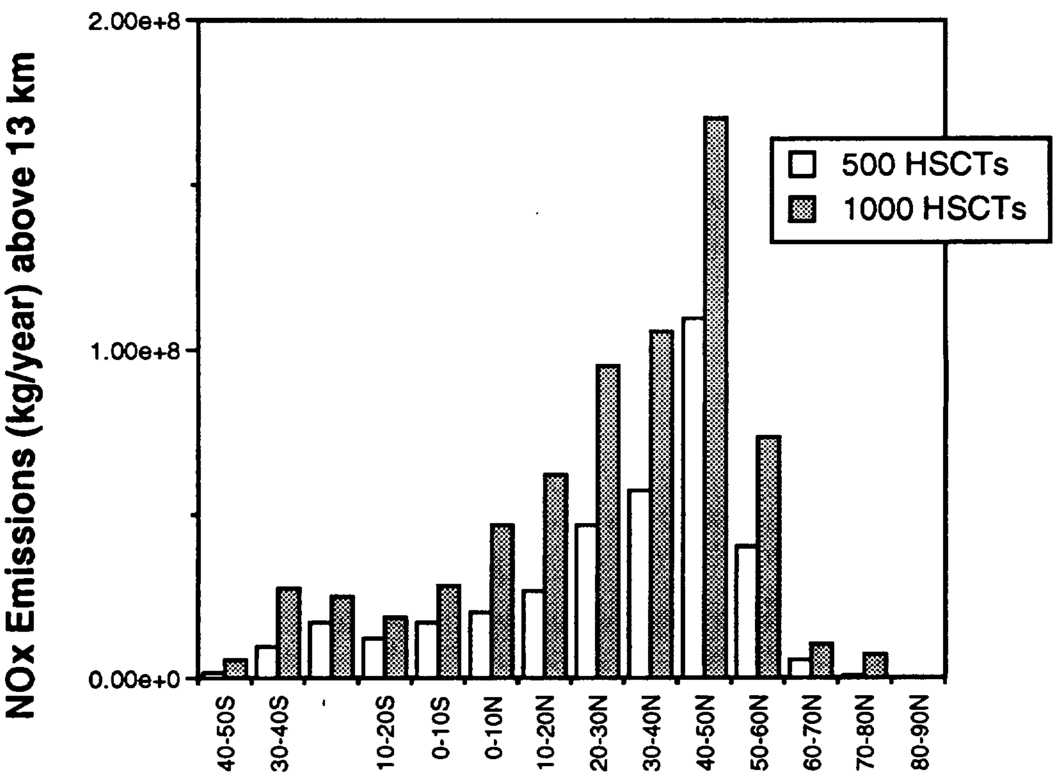


Figure 5-5. NOx emissions above 13 kilometers altitude as a function of latitude for 500 and 1000 Mach 2.4 HSCTs on the universal airline network.

To illustrate more clearly how the geographical distribution is modified as the fleet grows, Figure 5-6 shows the NOx emissions as a function of latitude for a fleet of 1000 Mach 2.4 HSCTs and compares them with the doubled emissions of the 500 HSCT fleet. In some regions (e.g., southern mid-latitudes, northern hemisphere tropics), the emissions have more than doubled compared with the 500 aircraft fleet; while in other regions (e.g., northern midlatitudes), the emissions have not grown linearly with the fleet size.

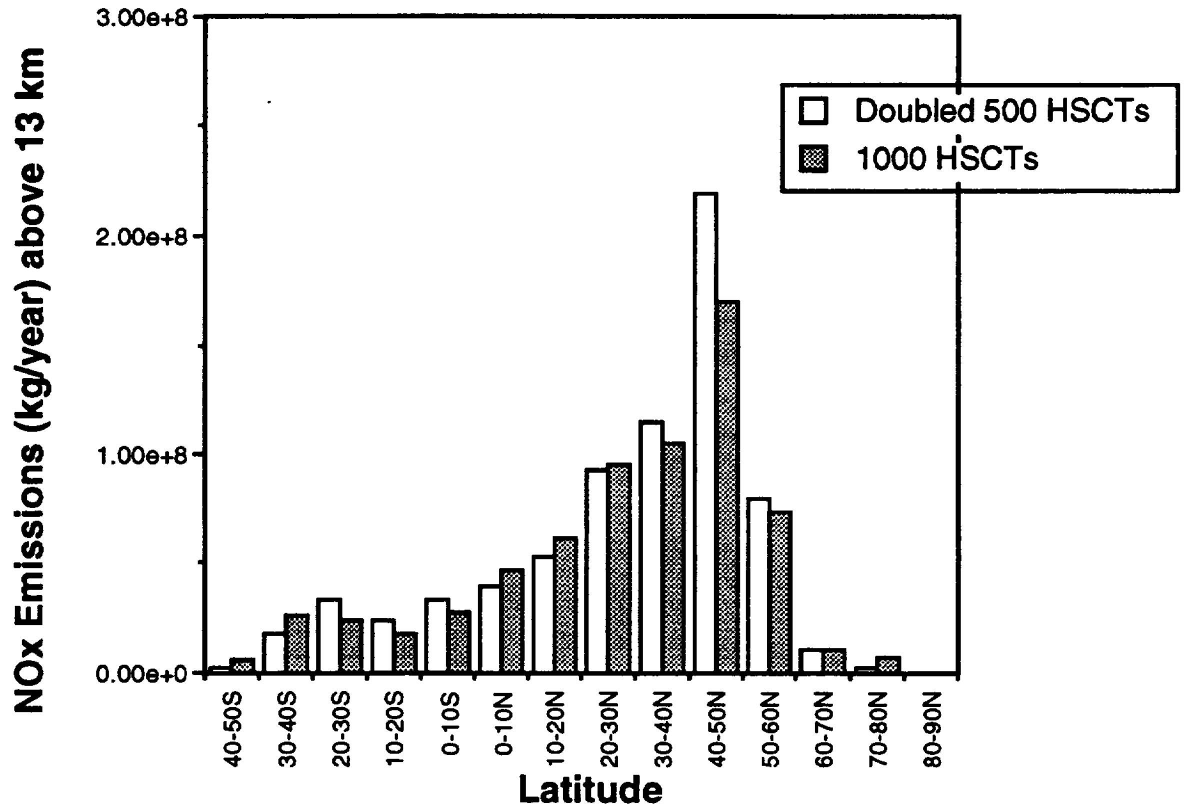


Figure 5-6. NOx emissions above 13 kilometers, comparing a fleet of 1000 HSCTs with doubling the results for a 500 HSCT fleet on the universal airline network.

Although the emission in all latitude bands do not exactly double when the fleet size doubles, the differences are relatively small in most regions. To first order, for 2-dimensional model calculations, treating the fleet size as a scalar appears to be justified. Subtle effects due to transport processes in the tropics or 3-dimensional effects will need to be evaluated for their sensitivity. The scenarios developed here should be useful for that purpose.

As shown, simply doubling the number of airplanes flown may not accurately reflect the distribution of emissions. A higher resolution comparison of the 1000 and doubled 500 HSCT fleet is shown in Figure 5-7. The top panel

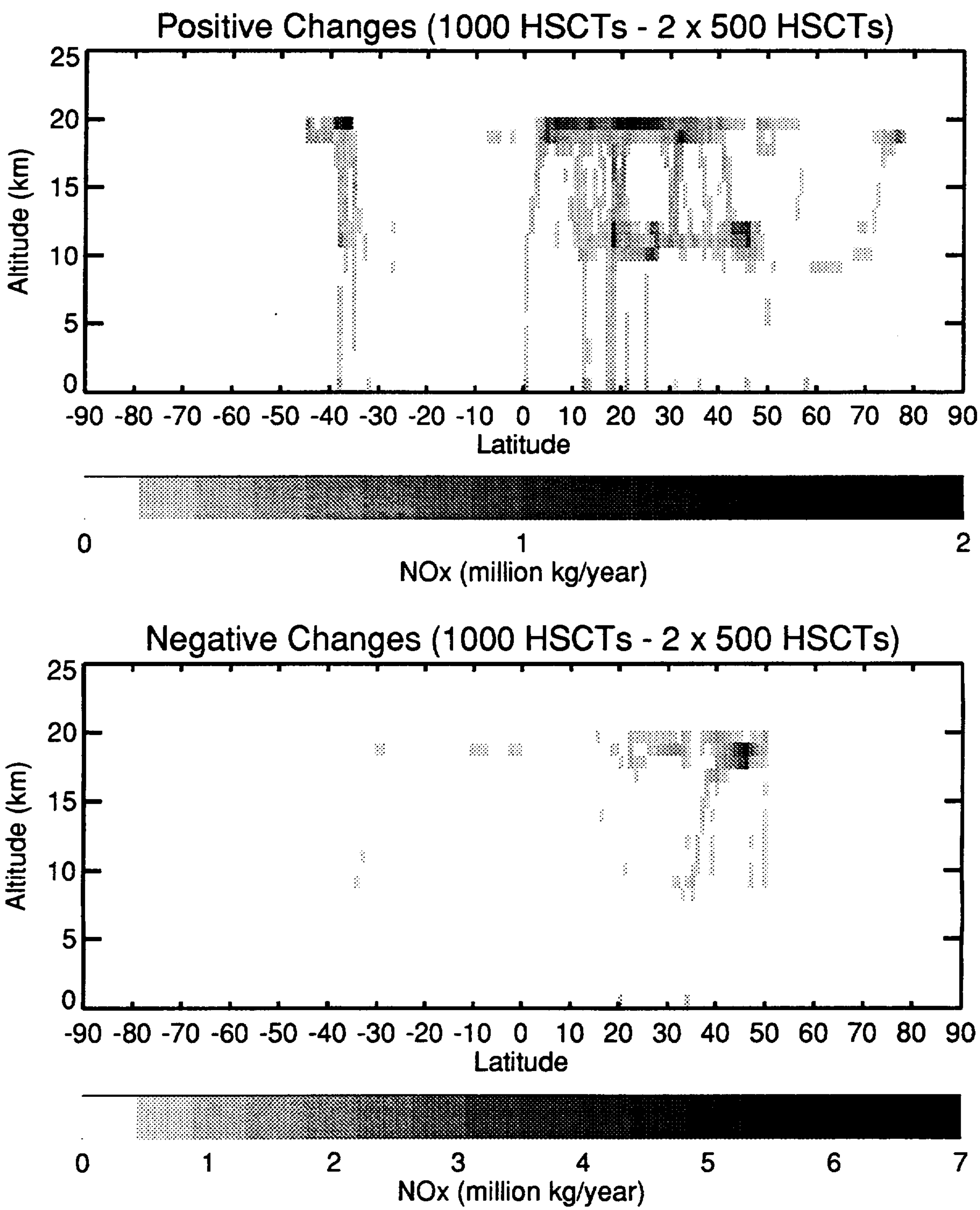


Figure 5-7. Comparison of NOx emissions from the 1000 HSCT fleet with emissions from doubling the 500 HSCT fleet on the universal airline network for Mach 2.4 [EI(NOx)=5] HSCTs. The top panel shows positive changes, while the bottom panel shows negative changes. (summed over longitude)

of Figure 5-7 shows the regions where the 1000 HSCT fleet has more than twice the emission levels of the 500 HSCT fleet. The bottom panel shows the locations where the emissions from the larger fleet are less than twice those of the smaller fleet. The bottom panel illustrates that flights in northern midlatitudes are projected to saturate and not increase linearly with fleet size. By contrast, emissions in the Southern hemisphere (particularly between 30-45° S latitude) and in the northern tropics (0-30° N latitude) are projected to increase faster than linear. In addition, emissions for the larger fleet at subsonic cruise altitudes would increase as new routes are added.

An increase of the fleet size from 500 to 1000 HSCTs would essentially double the total emissions from the HSCT fleet. However, as illustrated in Figure 5-7, the increase in fleet size shows growth in different geographical regions. As the fleet size increases, routes between new city pairs are introduced (see Appendix C).

Figure 5-8 shows the differences in fuel burned and NOx emissions as a function of latitude (summed over longitude) between the 1000 HSCT fleet and doubling the 500 HSCT fleet. The top two figures show the results considering all altitudes, while the bottom two figures consider only altitudes above 13 kilometers. For stratospheric NOx, emissions at southern mid-latitudes and the northern hemisphere tropics have grown faster than linear when the fleet increases from 500 to 1000 HSCTs, while northern mid-latitude emissions have increased at less than a linear rate.

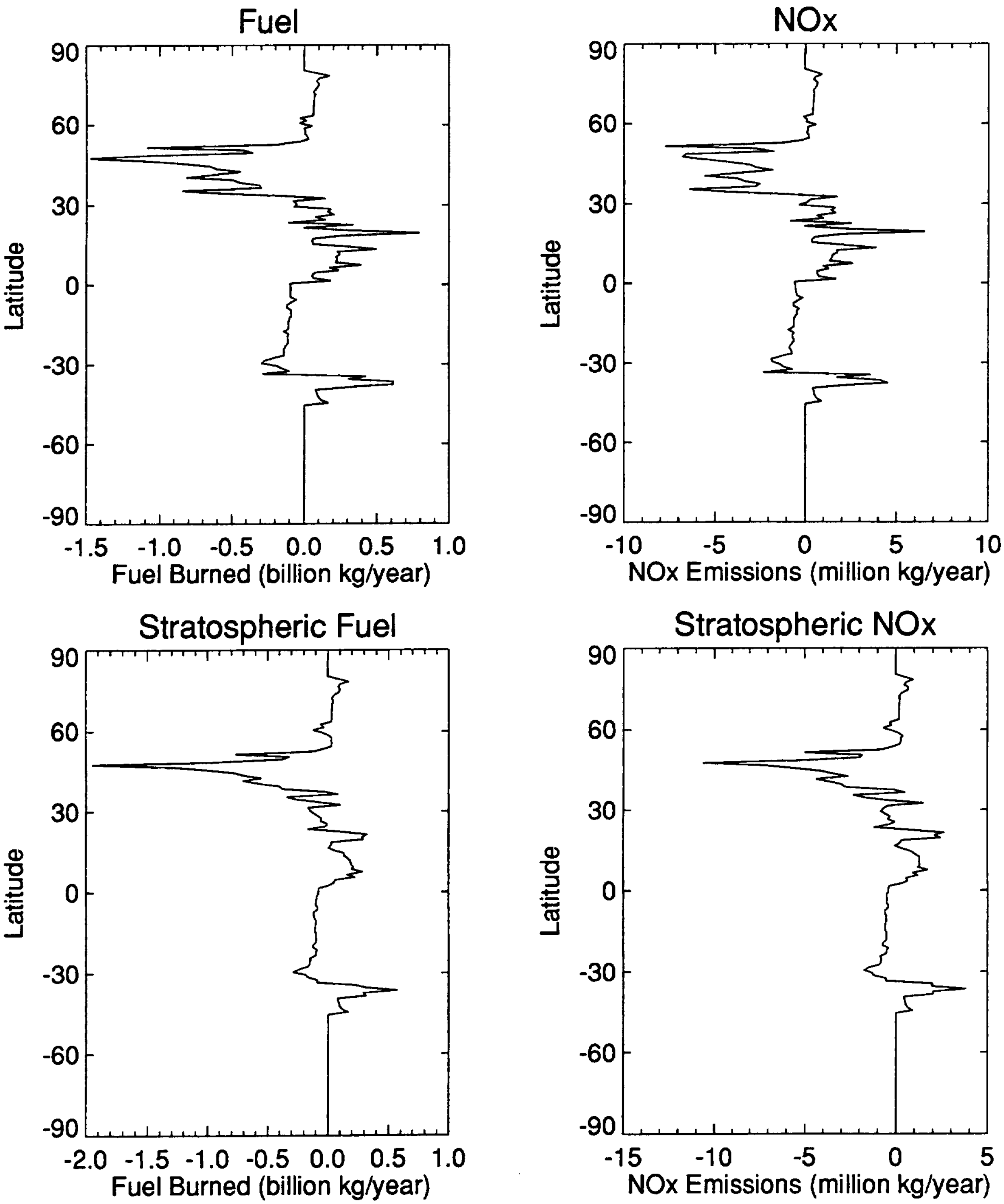


Figure 5-8. Differences in fuel burn and NOx emissions between 1000 HSCTs and simply doubling the 500 HSCT fleet, plotted as a function of latitude for the new universal HSCT network (Mach 2.4 HSCTs with EI(NOx) at cruise of approximately 5). Stratospheric emissions here refer to emissions above 13 km.

As shown in Figure 5-9, the relative partitioning of emissions between the northern and southern hemisphere is unchanged as the fleet doubles in size.

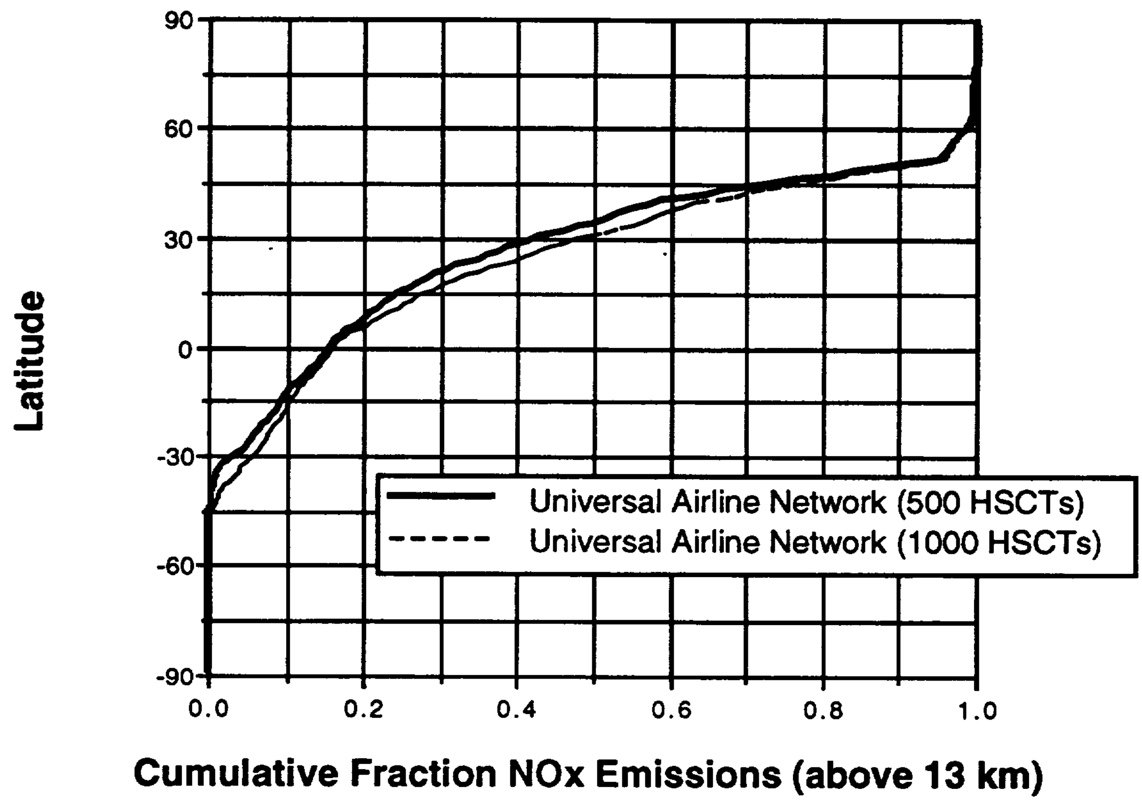


Figure 5-9. Cumulative fraction of stratospheric NOx emissions as a function of latitude for the 500 and 1000 HSCT fleets on the universal airline network.

5.3 Comparison of Fleet Growth Effects on 2015 Subsonic Emissions Inventory

The effect of a fleet of HSCTs on the subsonic fleet is summarized in Table 5-3. As discussed earlier, the corrections made to the P900 subsonic aircraft performance data files changed the global emissions by about 2%.

Not surprisingly, the fuel burn and emissions from the subsonic fleet decrease as more HSCTs are introduced into service. A fleet of HSCTs results in a drop of about 11% and 21% in total subsonic fleet fuel use for fleets of 500 and 1000 HSCTs, respectively, as HSCTs displace subsonic aircraft. The combined fuel use of subsonic and HSCT fleets will be discussed in Section 5.4.

Table 5-3. Comparison of the fuel use and emissions for the subsonic scheduled passenger fleets with and without the HSCT fleets

Year 2015 Subsonic Passenger fleet	Fuel (kg/year)	NOx (kg/year)	HC (kg/year)	CO (kg/year)
No HSCT fleet exists (Baughcum, *et. al.*, 1994)	2.45E+11	2.24E+09	9.20E+07	1.09E+09
No HSCT fleet exists (revised)	2.50E+11	2.32E+09	9.94E+07	1.11E+09
In the presence of 500 M2.4 HSCTs (universal network)	2.22E+11	2.05E+09	9.34E+07	1.05E+09
In the presence of 1000 M2.4 HSCTs (universal network)	1.97E+11	1.80E+09	8.71E+07	9.78E+08

5.4 Total 2015 Scheduled Aircraft Emissions for Fleets of 0, 500, and 1000 HSCTs

The total global emissions for all projected scheduled air traffic scenarios for 2015 are summarized in Table 5-4. Since the HSCT uses more fuel on a per passenger mile basis than do subsonic aircraft, global jet fuel use is greater for the scenarios in which HSCTs are included in the projections. Fuel usage by scheduled passenger traffic in 2015 with a fleet of 500 HSCTs or 1000 HSCTs is projected to be 21% and 40% higher, respectively, compared to an all subsonic fleet.

These numbers shown in Table 5-4 include only air traffic due to scheduled subsonic passenger jets, cargo jets, turboprop aircraft, and HSCTs. They do not include charter traffic, military, or most of the projected air traffic in the former Soviet Union. As discussed in Chapter 2, the traffic forecasts for year 2015 are projected based on current air traffic schedules which do not include much of the internal air traffic within the former Soviet Union. Projections of charter, military, and former Soviet Union traffic have been done previously by McDonnell Douglas under contract to NASA. (Landau, *et. al.* 1994).

Comparisons of NOx emissions as a function of altitude for scheduled air traffic, with and without an HSCT fleet, were made in our previous work (Baughcum, *et. al.*, 1994) and will not be repeated here. The data necessary for such calculations is included in Appendices F, G, and H of this report.

Table 5-4. Summary of fuel use, NOx, hydrocarbons, and carbon monoxide for the total scheduled air traffic scenarios for 2015.

	Fuel (kg/year)	NOx (kg/year)	HC (kg/year)	CO (kg/year)
Total 2015 Scheduled Air Traffic without an HSCT fleet	2.56E+11	2.37E+09	1.03E+08	1.14E+09
Total 2015 Scheduled Air Traffic with a 500 Mach 2.4 HSCT fleet (EI(NOx)=5) (universal network)	3.10E+11	2.63E+09	1.27E+08	1.32E+09
Total 2015 Scheduled Air Traffic with a 500 Mach 2.4 HSCT fleet (EI(NOx)=15) (universal network)	3.10E+11	3.58E+09	1.27E+08	1.32E+09
Total 2015 Scheduled Air Traffic with a 1000 Mach 2.4 HSCT fleet (EI(NOx)=5) (universal network)	3.59E+11	2.89E+09	1.49E+08	1.48E+09
Total 2015 Scheduled Air Traffic with a 1000 Mach 2.4 HSCT fleet (EI(NOx)=15) (universal network)	3.59E+11	4.67E+09	1.49E+08	1.48E+09
Total 2015 Scheduled Air Traffic with a 500 Mach 2.0 HSCT fleet (EI(NOx)=5) (universal network)	3.12E+11	2.60E+09	1.26E+08	1.32E+09
Total 2015 Scheduled Air Traffic with a 500 Mach 2.0 HSCT fleet (EI(NOx)=15) (universal network)	3.12E+11	3.57E+09	1.26E+08	1.32E+09
Total 2015 Scheduled Air Traffic with a 1000 Mach 2.0 HSCT fleet (EI(NOx)=5) (universal network)	3.62E+11	2.82E+09	1.47E+08	1.48E+09
Total 2015 Scheduled Air Traffic with a 1000 Mach 2.0 HSCT fleet (EI(NOx)=15) (universal network)	3.62E+11	4.67E+09	1.47E+08	1.48E+09

Note: NOx is given as gram equivalent NO_2

An evaluation of the effects of aircraft on the upper troposphere is one aspect of the NASA Atmospheric Effects of Aviation Project (AEAP). Based on these scenarios, the introduction of a fleet of Mach 2.4 (EI(NOx)=5) HSCTs would, change the NOx emissions due to aircraft at altitudes below 13 kilometers from 2.37 x 10^{10} kilograms/year to 2.27 x 10^{10} kilograms/year (-4%) for 500 HSCTs or to 2.15 x 10^{10} kilograms/year (-9%) for 1000 HSCTs. It is clear that the emissions of NOx above 13 kilometers (into the stratosphere) would be much higher with an HSCT fleet than without. As shown in Figure 5-10, the introduction of a fleet of HSCTs would be expected to decrease the NOx emissions in the upper troposphere.

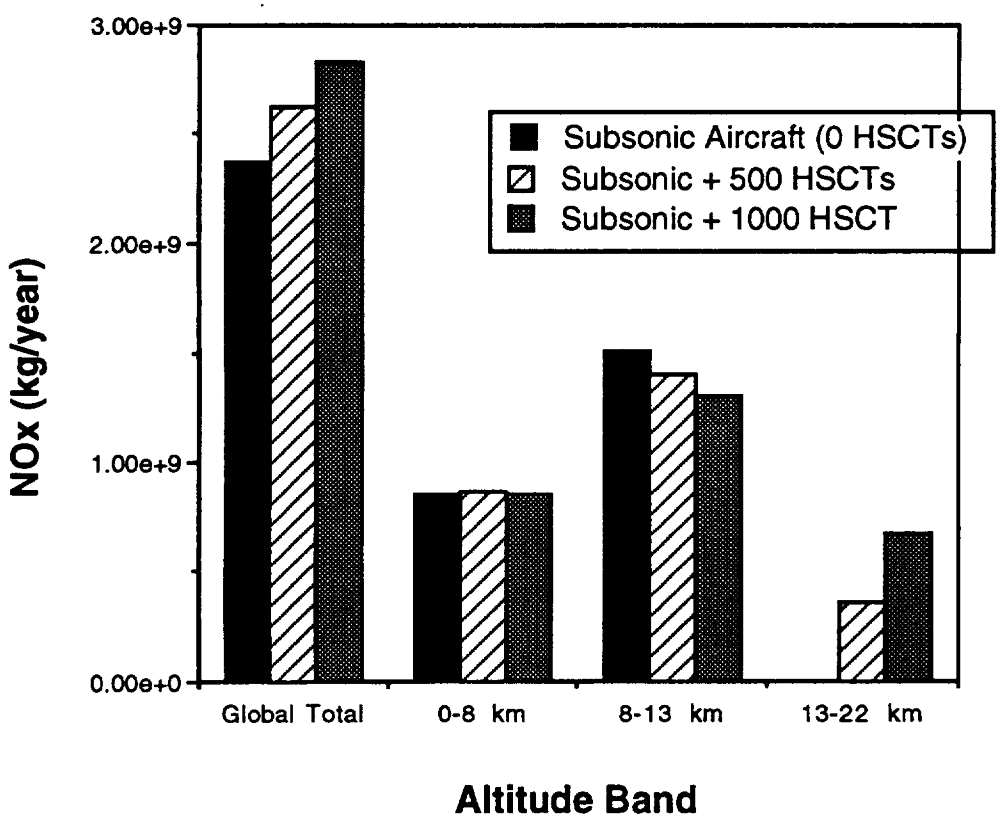


Figure 5-10. Total projected NOx emissions from 2015 scheduled air traffic for different altitude bands for fleets of 0, 500, and 1000 Mach 2.4 HSCTs with EI(NOx) at supersonic cruise of approximately 5.

5.5 Conclusions

A detailed database of projected 2015 subsonic and HSCT (both Mach 2.0 and 2.4) operational scenarios was developed using a universal airline network with HSCT fleet sizes of 0, 500, and 1000 active HSCTs. Three-dimensional data files of fuel burned and emissions (NOx, hydrocarbons, and carbon monoxide) on a 1° latitude x 1° longitude x 1 km altitude grid were calculated and delivered electronically to the Upper Atmospheric Data Program (UADP) system at the NASA Langley Research Center.

The work presented here shows that although the total global fuel burned and emissions from a fleet of 500 HSCTs is not very sensitive to whether the universal airline or the 1993 AESA assessment network is used, the geographical distribution of emissions at stratospheric cruise is sensitive to the market penetration assumptions used to distribute projected HSCT passenger demand.

An increase in HSCT fleet size from 500 to 1000 units has been shown to approximately double emissions at stratospheric cruise. However, as the fleet grows, emissions in different geographical regions grow at different rates. Consequently, stratospheric emissions in northern mid-latitudes are not projected to double as the fleet size doubles, while emissions in the northern tropics and southern hemisphere mid-latitudes are expected to more than double.

For an HSCT combustor with a NOx emission index of 5, the analyses show that the total NOx emissions below 13 kilometers altitude are not very sensitive to the presence or absence of an HSCT fleet. This suggests that to first-order the assessment of the effects of an HSCT fleet are largely decoupled from the assessment of subsonic aircraft effects. In some geographical regions, however, the changes may be greater (e.g., the North Atlantic).

The aircraft emissions inventories for scheduled air traffic developed in this study have been combined at NASA Langley with results for non-OAG scheduled operations (charter, military, and internal former Soviet Union) to create inventories of total aircraft emissions in the year 2015. These inventories are being used by the NASA Atmospheric Effects of Aviation Project (AEAP) in the 1995 AESA assessment of HSCT ozone impact.

5.6 Database Availability

The inventories of jet fuel burned and emissions (NOx, CO, total hydrocarbons) have been calculated for projected subsonic and HSCT fleets for the year 2015. These data will be available on a 1 degree latitude x 1 degree longitude x 1 km altitude grid by contacting Karen H. Sage (sage@uadp2.larc.nasa.gov) at NASA Langley Research Center or by sending a request to the Atmospheric Sciences Division, NASA Langley Research Center, Hampton, VA 23681-0001.

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Appendix A - World Passenger Demand Forecast

WORLD PASSENGER TRAFFIC FORECAST
RPMs IN MILLIONS

Regional Flow / Year	1991	Growth Rate 1991-1995	1995	Growth Rate 1995-2000	2000	Growth Rate 2000-2005	2005	Growth Rate 2005-2010	2010	Growth Rate 2010-2015	2015	Average Growth Rate 1991-2015
Intra & Domestic N. America	358,741	4.87%	433,867	4.66%	544,736	3.94%	660,974	3.51%	785,276	3.25%	921,565	4.01%
N. America-Europe	121,400	6.56%	156,540	5.36%	203,233	4.42%	252,344	4.06%	307,900	3.86%	372,129	4.78%
N. America-Asia/Pacific	87,065	7.94%	118,193	7.71%	171,327	7.07%	241,051	6.54%	330,855	6.11%	445,013	7.03%
Other N. America	3,565	5.50%	4,416	4.39%	5,474	3.96%	6,645	3.54%	7,907	3.31%	9,306	4.08%
N. America-Latin America	36,476	4.91%	44,191	5.91%	58,876	5.48%	76,883	4.92%	97,742	4.72%	123,092	5.20%
Intra & Domestic Europe	148,216	6.20%	188,512	5.04%	241,004	4.41%	299,023	4.15%	366,412	3.63%	437,999	4.62%
Europe-Asia/Pacific	46,430	12.34%	73,938	8.40%	110,684	7.53%	159,139	6.69%	219,963	6.24%	297,690	8.05%
Europe-Indian Sub Continent	9,718	2.08%	10,552	4.16%	12,938	3.74%	15,545	3.78%	18,713	3.64%	22,376	3.54%
Europe-Mid East	19,578	8.26%	26,897	4.94%	34,231	4.58%	42,821	4.22%	52,652	4.03%	64,163	5.07%
Europe-Africa	25,811	3.79%	29,950	5.57%	39,271	4.62%	49,215	4.32%	60,816	3.96%	73,850	4.48%
Europe-Latin America	26,869	8.11%	36,700	5.38%	47,689	4.78%	60,236	4.59%	75,387	4.43%	93,627	5.34%
Intra & Domestic Aisa/Pacific	86,003	8.92%	121,034	8.85%	184,989	7.93%	270,878	7.45%	388,063	6.65%	535,482	7.92%
Misc Long Range	40,348	3.99%	47,179	7.04%	66,288	6.05%	88,926	5.74%	117,570	5.37%	152,698	5.70%
Japan	33,773	5.26%	41,455	4.40%	51,413	4.22%	63,217	3.78%	76,119	3.39%	89,918	4.16%
Intra & Dom Indian Sub Continent	6,779	9.41%	9,714	5.54%	12,722	5.17%	16,367	4.95%	20,839	4.78%	26,316	5.81%
Other Indian Subcontinent	14,261	6.65%	18,449	4.69%	23,204	4.46%	28,858	4.25%	35,534	4.11%	43,461	4.75%
Intra & Domestic Mid East/Africa	18,455	8.00%	25,107	4.91%	31,904	4.43%	39,627	4.27%	48,849	4.09%	59,695	5.01%
Other African	8,002	11.33%	12,291	4.75%	15,500	4.28%	19,110	4.02%	23,276	3.88%	28,163	5.38%
Intra & Domestic Latin America	27,023	7.61%	36,239	5.25%	46,811	4.82%	59,232	4.63%	74,275	4.48%	92,463	5.26%
CIS International	13,842	-6.10%	10,761	7.14%	15,191	6.23%	20,555	5.18%	26,458	4.58%	33,098	3.70%
MAC Charter	5,657	-7.56%	4,131	-3.00%	3,547	-1.20%	3,339	-0.90%	3,191	0.00%	3,191	-2.36%
	1,138,012		1,450,116	5.79%	1,921,030	5.19%	2,473,985	4.87%	3,137,799	4.58%	3,925,296	5.29%

Appendix B - HSCT Route System Gateway Cities

City Code	City Name
ACA	Acapulco, Mexico
AKL	Auckland, New Zealand
AMS	Amsterdam, The Netherlands
ANC	Anchorage, Alaska, USA
ATH	Athens, Greece
ATL	Atlanta, Georgia, USA
BAH	Bahrain, Bahrain
BER	Berlin, Germany
BKK	Bangkok, Thailand
BOG	Bogota, Columbia
BOM	Bombay, India
BOS	Boston, Massachusetts, USA
BRU	Brussels, Belgium
BUE	Buenos Aires, Argentina
CAI	Cairo, Egypt
CAN	Guangzhou, China
CCS	Caracas, Venezuela
CHI	Chicago, Illinois, USA
CMB	Colombo, Sri Lanka
CPH	Copenhagen, Denmark
CVG	Cincinnati, Ohio, USA
DEL	Delhi, India
DFW	Dallas, Texas, USA
DHA	Dharan, Saudia Arabia
DKR	Dakar, Senegal
DTW	Detroit, Michigan, USA
FDF	Fort-de-France, Martinique
FRA	Frankfurt, Germany
GUM	Guam, Guam
GVA	Geneva, Switzerland
HAV	Havana, Cuba
HEL	Helsinki, Finland
HKG	Hong Kong, Hong Kong
HNL	Honolulu, Hawaii, USA
HOU	Houston, Texas, USA
JKT	Jakarta, Indonesia
JNB	Johannesburg, South Africa
KHI	Karachi, Pakistan
KHV	Khabarovsk, Russian Federation
LAX	Los Angeles, California, USA
LIM	Lima, Peru
LIS	Losbon, Portugal
LON	London, England, UK
MAD	Madrid, Spain
MEL	Melbourne, Australia
MEX	Mexico City, Mexico

City Code	City Name
MIA	Miami, Florida, USA
MIL	Milan, Italy
MNL	Manila, Philippines
MOW	Moscow, Russian Republic
MRU	Mauritius, Mauritius
MSP	Minneapolis-St, Paul, Minnesota, USA
MUC	Munich, Germany
NAN	Nandi, Fiji
NYC	New York, New York, USA
OSA	Osaka, Japan
OSL	Oslo, Norway
PAR	Paris, France
PEK	Beijing, China
PER	Perth, Autralia
PHL	Philadelphia, Pennsylvania, USA
PPT	Papeete, Tahiti, French Polynesia
PTY	Panama City, Panama
RIO	Rio de Janeiro, Brasil
ROM	Rome, Italy
SCL	Santiago, Chile
SEA	Seattle, Washington, USA
SEL	Seoul, Korea
SFO	San Francisco, California, USA
SHA	Shanghai, China
SIN	Singapore, Singapore
SJU	San Juan, Puerto Rico
SNN	Shannon, Ireland
STL	Saint Louis, Missouri, USA
STO	Stockholm, Sweden
SYD	Sydney, Australia
TLV	Tel Aviv, Israel
TPE	Taipei, Taiwan
TYO	Tokyo, Japan
VIE	Vienna, Austria
WAS	Washington, DC, USA
WAW	Warsaw, Poland
YHZ	Halifax, Nova Scotia, Canada
YMQ	Montreal, Quebec, Canada
YVR	Vancouver, British Columbia, Canada
YYC	Calgary, Alberta, Canada
YYZ	Toronto, Ontario, Canada

Appendix C. Departure Statistics

This appendix is a table of departure statistics for the universal network for a fleets of 500 and 1000 active Mach 2.4 HSCTs. For each gateway city-pair, flight distances for the great circle route, supersonic flight legs, and total path length are given in nautical miles. Stops enroute are identified in the column marked via. Block time and total trip times are given in hours with the fraction of time compared to an all subsonic flight. Daily departures and load factors are shown for both fleets of 500 and 1000 HSCTs. The first section of the table shows city pairs used by the 500 unit fleet, while the second section includes flights used only by the 1000 unit fleet.

				Distance (n.m.)			Time (hours)			500 Units		1000 Units	
Origin	Dest	Via	Via	GC	Cruise	Path	Block	Trip	Percent subsonic	Daily Departures	Load Factor	Daily Departures	Load Factor
AKL	HKG	POM		4937	3757	5085	5.45	6.45	60	4	61	4	67
AKL	HNL			3826	3165	3825	3.58	3.58	43	22	66	26	66
AKL	JKT			4123	3751	4530	4.19	4.19	46	2	67	2	67
AKL	LAX	HNL		5659	4817	6042	5.96	6.96	57	16	68	20	68
AKL	OSA			4834	3936	4833	4.53	4.53	43	2	67	4	65
AKL	PER			2879	2614	3236	3.14	3.14	49	14	63	24	63
AKL	PPT			2209	1635	2210	2.39	2.39	47	10	66	24	65
AKL	SFO	HNL		5671	4691	5907	5.86	6.86	56	8	68	8	68
AKL	SIN			4541	4055	4833	4.38	4.38	44	4	67	4	67
AKL	TYO			4768	3918	4766	4.43	4.43	43	6	67	8	63
AKL	YVR	HNL		6130	4913	6174	6.10	7.10	54	4	68	8	68
AMS	ATL			3812	2844	4001	4.31	4.31	51	4	67	6	67
AMS	CCS			4230	3239	4232	4.26	4.26	46	14	64	16	66
AMS	CHI			3567	2214	3876	4.85	4.85	61	2	67	4	67
AMS	DFW			4262	2819	4630	5.53	5.53	59	2	67	4	67
AMS	DTW			3412	2218	3672	4.46	4.46	59	4	67	10	63
AMS	MIA			4015	3048	4038	4.13	4.13	47	2	65	2	67
AMS	MSP			3607	2716	4017	4.50	4.50	56	2	67	4	67
AMS	NYC			3155	2325	3247	3.52	3.52	50	12	62	20	61
AMS	YMQ			2972	2267	3347	3.78	3.78	57	2	67	4	67
AMS	YVR			4160	2661	4483	5.45	5.45	60	4	67	6	67
AMS	YYZ			3232	2238	3517	4.14	4.14	58	2	67	4	67
ANC	HKG			4397	3835	4892	4.77	4.77	50	2	67	2	67
ANC	TPE			4057	3244	4234	4.26	4.26	48	8	66	10	67
ATH	NYC			4273	2520	4317	5.31	5.31	57	10	62	14	61
ATL	BER			4089	3141	4415	4.73	4.73	53	4	61	4	67
ATL	FRA			3997	2948	4214	4.59	4.59	52	6	67	10	64
ATL	GVA			4005	2898	4135	4.50	4.50	51	2	67	2	67
ATL	LON			3648	2906	3806	3.87	3.87	48	10	62	12	67
ATL	MAD			3756	2826	3848	4.05	4.05	49	2	67	2	67
ATL	MUC			4155	2879	4340	4.91	4.91	54	4	60	4	67

				Distance (n.m.)			Time (hours)			500 Units		1000 Units	
Origin	Dest	Via	Via	GC	Cruise	Path	Block	Trip	Percent subsonic	Daily Departures	Load Factor	Daily Departures	Load Factor
ATL	PAR			3806	2897	3965	4.18	4.18	50	2	67	2	67
ATL	SNN			3327	2656	3476	3.55	3.55	48	2	67	2	67
BAH	BKK			2893	2239	3460	4.03	4.03	62	4	67	16	61
BAH	CMB			2024	1008	2093	2.93	2.93	62	2	67	22	65
BAH	HKG			3449	3484	4743	4.92	4.92	64	2	67	6	67
BAH	JKT			3801	2515	3861	4.46	4.46	53	4	67	6	66
BAH	MNL			3976	3407	4671	4.89	4.89	56	6	67	8	67
BAH	SIN			3412	2501	3663	4.10	4.10	54	16	62	26	63
BER	BOS			3274	2202	3444	4.04	4.04	55	2	65	2	67
BER	CHI			3820	2202	4189	5.46	5.46	65	2	67	6	62
BER	DFW			4517	2803	4943	6.15	6.15	62	2	67	2	67
BER	MIA			4311	3333	4440	4.54	4.54	48	4	67	4	67
BER	NYC			3436	2312	3559	4.13	4.13	54	10	61	16	63
BER	WAS			3627	2379	3748	4.41	4.41	55	2	67	4	67
BER	YVR			4306	2681	4670	5.78	5.78	61	2	62	2	67
BKK	OSA			2259	2343	3009	3.05	3.05	59	6	67	24	67
BKK	PER			2889	1844	3077	3.79	3.79	58	2	67	6	67
BKK	SEL			1989	2137	2783	2.87	2.87	62	2	67	22	63
BKK	TYO			2505	2459	3111	3.10	3.10	54	20	65	50	66
BOG	MAD			4333	2971	4334	4.79	4.79	50	2	62	2	67
BOM	SIN			2110	1965	2545	2.62	2.62	54	2	67	12	61
BOS	FRA			3177	2270	3286	3.66	3.66	52	2	67	2	67
BOS	GVA			3185	2275	3270	3.62	3.62	51	2	67	4	67
BOS	LON			2827	2275	2937	2.99	2.99	47	14	62	24	62
BOS	PAR			2985	2271	3100	3.31	3.31	49	4	67	8	67
BOS	SNN			2506	2021	2607	2.67	2.67	47	2	67	4	67
BRU	CHI			3602	2289	3868	4.74	4.74	60	2	67	4	61
BRU	NYC			3176	2401	3239	3.41	3.41	48	10	67	18	62
BRU	WAS			3370	2467	3428	3.69	3.69	49	2	67	2	67
BRU	YMQ			3000	2343	3339	3.67	3.67	55	2	67	4	66
BUE	LON	DKR		6009	5207	6525	6.41	7.41	57	4	67	4	67

				Distance (n.m.)			Time (hours)			500 Units		1000 Units	
Origin	Dest	Via	Via	GC	Cruise	Path	Block	Trip	Percent subsonic	Daily Departures	Load Factor	Daily Departures	Load Factor
BUE	MAD	DKR		5441	4401	5870	6.14	7.14	61	12	67	20	64
BUE	PAR	DKR		5989	5126	6549	6.55	7.55	58	8	67	8	67
CAN	LAX	TYO		6282	5180	6652	6.65	7.65	57	4	67	4	67
CCS	FRA			4357	3262	4359	4.48	4.48	47	2	67	4	67
CCS	LIS			3508	2878	3509	3.34	3.34	43	2	67	4	67
CCS	LON			4031	3354	4073	3.82	3.82	43	2	67	2	67
CCS	MAD			3780	2925	3781	3.80	3.80	46	10	67	14	65
CCS	MIL			4347	3297	4348	4.41	4.41	46	2	67	2	67
CCS	NYC			1837	1359	1897	2.13	2.13	49	4	67	20	62
CCS	PAR			4118	3213	4109	4.06	4.06	45	4	67	6	61
CCS	ROM			4497	2906	4498	5.17	5.17	53	2	67	2	67
CHI	FRA			3761	2269	4030	5.08	5.08	61	6	67	12	63
CHI	GVA			3806	2274	4014	5.04	5.04	60	4	60	6	67
CHI	HNL			3678	1508	3680	5.34	5.34	66	4	67	10	62
CHI	LON			3423	2274	3681	4.41	4.41	58	14	67	26	66
CHI	MUC			3922	2456	4178	5.13	5.13	59	4	60	6	65
CHI	OSA	SEA		5614	3667	5959	7.45	8.45	70	4	67	12	67
CHI	PAR			3595	2271	3844	4.72	4.72	59	4	67	8	67
CHI	ROM			4176	2415	4364	5.53	5.53	60	2	64	2	67
CHI	TYO	SEA		5435	3397	5636	7.18	8.18	69	8	67	24	67
CPH	NYC			3339	2849	3480	3.32	3.32	45	6	67	8	67
CPH	SEA			4214	2738	4592	5.56	5.56	60	2	63	2	67
CVG	FRA			3777	2384	3911	4.71	4.71	57	2	67	4	61
CVG	LON			3432	2389	3562	4.04	4.04	53	2	67	2	67
DFW	FRA			4455	2871	4784	5.76	5.76	59	2	67	2	67
DFW	HNL			3280	1725	3282	4.32	4.32	59	2	67	6	67
DFW	LON			4115	2880	4435	5.09	5.09	56	8	67	12	65
DFW	MAD			4303	2803	4477	5.27	5.27	56	2	67	4	62
DFW	PAR			4286	2871	4594	5.40	5.40	58	4	67	6	67
DFW	TPE	SEA	TYO	6691	4058	6772	8.69	10.69	67	12	68	18	68
DHA	JKT			3824	2514	3880	4.49	4.49	53	2	67	4	67

				Distance (n.m.)			Time (hours)			500 Units		1000 Units	
Origin	Dest	Via	Via	GC	Cruise	Path	Block	Trip	Percent subsonic	Daily Departures	Load Factor	Daily Departures	Load Factor
DHA	MNL			4001	3406	4690	4.92	4.92	56	6	67	10	61
DHA	SIN			3436	2500	3682	4.13	4.13	54	2	67	2	67
DKR	HAV			3691	3043	3692	3.48	3.48	43	2	67	4	60
DTW	FRA			3603	2273	3826	4.68	4.68	59	2	63	2	67
DTW	PAR			3430	2396	3615	4.13	4.13	54	2	67	2	67
FDF	FRA			3909	2878	3948	4.17	4.17	49	2	67	4	67
FDF	LON			3590	2922	3635	3.52	3.52	44	10	62	12	67
FDF	MAD			3313	2523	3359	3.49	3.49	47	8	67	14	60
FDF	PAR			3668	2826	3699	3.76	3.76	46	22	63	28	65
FRA	HOU			4545	2949	4786	5.67	5.67	57	2	67	4	67
FRA	MIA			4188	3140	4239	4.40	4.40	48	6	67	8	65
FRA	NYC			3339	2380	3401	3.74	3.74	50	20	66	32	63
FRA	PHL			3420	2427	3476	3.83	3.83	50	2	67	2	67
FRA	WAS			3534	2447	3590	4.02	4.02	51	6	67	8	67
FRA	YMQ			3161	2323	3502	4.01	4.01	57	2	64	4	62
FRA	YVR			4351	2719	4675	5.74	5.74	60	4	66	6	65
FRA	YYC			4062	2776	4345	5.05	5.05	57	2	62	2	66
FRA	YYZ			3422	2293	3671	4.37	4.37	57	2	67	6	62
GUM	HNL			3296	2679	3298	3.18	3.18	43	14	62	18	64
GUM	SYD			2869	2461	3058	2.99	2.99	46	2	66	4	53
GUM	TYO			1358	829	1356	1.74	1.74	52	2	66	36	63
GVA	NYC			3346	2385	3385	3.71	3.71	50	10	64	16	61
GVA	YMQ			3191	2314	3483	3.98	3.98	56	4	67	8	65
HEL	NYC			3565	2590	3742	4.13	4.13	52	2	67	6	60
HKG	HNL			4812	4075	4842	4.37	4.37	42	4	67	6	64
HKG	JKT			1761	1245	1782	2.04	2.04	49	4	67	20	61
HKG	LAX	TYO		6283	5175	6591	6.54	7.54	56	60	68	68	68
HKG	MEL			3992	3857	4912	4.78	4.78	54	2	67	4	67
HKG	PER			3256	2908	3545	3.37	3.37	46	4	61	4	67
HKG	SEA	TYO		5625	4713	6010	6.02	7.02	58	4	68	4	68
HKG	SFO	TYO		5994	5022	6306	6.20	7.20	56	24	68	28	68

				Distance (n.m.)			Time (hours)			500 Units		1000 Units	
Origin	Dest	Via	Via	GC	Cruise	Path	Block	Trip	Percent subsonic	Daily Departures	Load Factor	Daily Departures	Load Factor
HKG	SIN			1392	879	1397	1.75	1.75	52	10	60	94	67
HKG	SYD			3981	3810	4532	4.12	4.12	47	12	61	14	65
HKG	TYO			1585	1316	1865	2.12	2.12	56	6	49	80	64
HKG	YVR	TYO		5533	4548	5935	6.08	7.08	59	32	67	40	68
HNL	HOU			3396	1852	3391	4.37	4.37	58	2	67	4	67
HNL	JKT	GUM		5825	4786	6000	5.93	6.93	55	4	67	8	68
HNL	LAX			2216	1652	2217	2.38	2.38	47	36	63	84	66
HNL	MEL			4789	3764	4799	4.68	4.68	45	6	58	6	65
HNL	MNL			4597	3845	4599	4.20	4.20	42	20	61	22	62
HNL	OSA			3557	2846	3567	3.49	3.49	44	52	66	68	65
HNL	PPT			2383	1822	2383	2.49	2.49	46	8	62	16	63
HNL	SEA			2324	1723	2325	2.50	2.50	47	4	67	12	67
HNL	SEL			3950	3651	4440	4.15	4.15	48	12	67	16	66
HNL	SFO			2080	1525	2082	2.28	2.28	47	14	64	36	64
HNL	STL			3579	1530	3581	5.12	5.12	65	2	67	6	61
HNL	SYD			4409	3707	4419	4.03	4.03	42	20	64	24	63
HNL	TPE			4394	3670	4395	4.04	4.04	42	2	67	4	61
HNL	TYO			3311	2634	3312	3.26	3.26	44	90	66	124	66
HNL	YVR			2347	1747	2349	2.52	2.52	47	4	66	10	61
HOU	LON			4200	2908	4377	4.95	4.95	54	6	67	8	66
HOU	PAR			4365	2898	4536	5.26	5.26	55	2	67	4	67
JKT	OSA			2940	2541	3183	3.13	3.13	48	4	67	6	67
JKT	SEL			2849	2337	2957	2.95	2.95	46	2	67	4	67
JKT	SYD			2968	3291	3997	3.76	3.76	56	8	65	18	62
JKT	TPE			2053	1516	2126	2.37	2.37	50	4	67	12	67
JKT	TYO			3145	2657	3285	3.18	3.18	45	8	67	12	64
JNB	RIO			3859	2599	3859	4.35	4.35	51	18	65	24	65
JNB	SIN			4666	3585	4729	4.77	4.77	47	2	67	2	67
JNB	SYD	PER		5948	5659	7173	7.08	8.08	63	4	67	4	67
LAX	LON			4727	2468	4945	6.55	6.55	64	18	66	28	64
LAX	MEL	HNL		6884	5416	7016	7.06	8.06	50	12	68	12	68

				Distance (n.m.)			Time (hours)			500 Units		1000 Units	
Origin	Dest	Via	Via	GC	Cruise	Path	Block	Trip	Percent subsonic	Daily Departures	Load Factor	Daily Departures	Load Factor
LAX	MNL	TYO		6335	4942	6372	6.41	7.41	54	4	68	4	68
LAX	NAN			4798	4019	4799	4.36	4.36	42	2	67	2	67
LAX	OSA			4956	3790	4957	4.95	4.95	46	40	64	44	66
LAX	PEK	TYO		5416	4929	6373	6.43	7.43	63	4	67	4	67
LAX	PPT			3566	2929	3567	3.39	3.39	43	6	65	8	62
LAX	SEL	TYO		5178	3859	5390	6.10	7.10	63	32	67	52	67
LAX	SIN	TYO		7612	6159	7626	7.32	8.32	47	4	68	8	68
LAX	SYD	HNL		6508	5359	6636	6.41	7.41	48	48	68	48	68
LAX	TPE	TYO		5894	4520	5913	6.04	7.04	55	40	66	44	67
LAX	TYO			4724	3859	4726	4.43	4.43	43	58	64	66	63
LIM	MIA			2276	1167	2402	3.03	3.03	58	8	60	18	64
LIM	NYC			3164	1710	3379	3.87	3.87	55	2	67	4	67
LIS	NYC			2915	2291	2916	2.93	2.93	45	6	67	10	66
LIS	RIO			4163	3594	4336	4.02	4.02	44	10	62	12	60
LON	MIA			3835	3111	3843	3.69	3.69	44	22	61	26	64
LON	MSP			3476	2511	3857	4.45	4.45	58	2	67	6	61
LON	NYC			2989	2386	3052	3.08	3.08	46	50	66	80	65
LON	PHL			3070	2432	3127	3.16	3.16	46	6	66	10	60
LON	RIO	DKR		4993	4127	5376	5.55	6.55	60	4	67	8	67
LON	SEA			4156	2479	4376	5.47	5.47	60	4	67	6	67
LON	SFO			4649	2468	4851	6.38	6.38	63	6	67	10	67
LON	SJU			3633	2930	3634	3.51	3.51	44	2	67	4	67
LON	STL			3638	2343	3824	4.59	4.59	57	4	62	6	67
LON	SYD	GDX	GUM	9184	7181	9860	10.53	12.53	60	6	67	12	63
LON	TYO	GDX		5175	3519	5560	6.63	7.63	68	12	67	40	62
LON	WAS			3184	2452	3241	3.35	3.35	47	18	62	26	64
LON	YMQ			2817	2327	3153	3.34	3.34	53	4	67	8	67
LON	YVR			4090	2458	4323	5.40	5.40	60	4	67	8	61
LON	YYC			3786	2513	3994	4.71	4.71	56	4	67	8	60
LON	YYZ			3079	2298	3322	3.70	3.70	54	14	67	28	62
MAD	MEX			4892	3203	4893	5.17	5.17	49	8	67	10	62

				Distance (n.m.)			Time (hours)			500 Units		1000 Units	
Origin	Dest	Via	Via	GC	Cruise	Path	Block	Trip	Percent subsonic	Daily Departures	Load Factor	Daily Departures	Load Factor
MAD	MIA			3835	2993	3836	3.82	3.82	45	4	67	6	67
MAD	NYC			3109	2327	3124	3.28	3.28	47	10	67	18	60
MAD	RIO			4396	3594	4592	4.50	4.50	47	10	67	12	65
MAD	WAS			3306	2394	3313	3.56	3.56	48	2	67	2	67
MEL	OSA			4378	3733	4808	4.74	4.74	49	2	67	2	67
MEL	PPT			3614	2788	3614	3.65	3.65	46	6	66	8	65
MEL	SFO	HNL		6828	5289	6881	6.96	7.96	49	4	68	4	68
MEL	SIN			3258	3652	4679	4.59	4.59	63	6	61	14	65
MEL	TYO			4412	3717	4763	4.67	4.67	48	4	67	6	66
MIA	MUC			4339	3071	4364	4.72	4.72	50	4	66	4	67
MIA	PAR			3976	3090	3989	3.99	3.99	46	6	64	6	66
MIA	RIO			3624	3983	4781	4.38	4.38	55	12	67	20	65
MIA	ROM			4493	3232	4495	4.77	4.77	49	4	62	4	67
MIA	SCL			3592	2983	3689	3.55	3.55	45	4	67	6	67
MIL	NYC			3459	2542	3529	3.79	3.79	49	14	65	20	66
MIL	WAS			3656	2607	3718	4.07	4.07	50	2	61	2	67
MNL	SYD			3380	3196	3920	3.73	3.73	50	2	67	4	64
MNL	TYO			1645	1083	1646	1.98	1.98	51	4	66	24	66
MOW	NYC			4036	2573	4207	5.03	5.03	57	4	62	6	61
MUC	NYC			3496	2569	3549	3.79	3.79	49	12	61	16	65
MUC	WAS			3691	2635	3738	4.07	4.07	50	2	67	4	67
MUC	YVR			4501	2679	4828	6.08	6.08	62	2	65	2	67
MUC	YYC			4216	2736	4499	5.39	5.39	58	2	62	2	67
NAN	PAR	ANC		8908	7057	9143	9.08	10.08	49	4	67	4	67
NYC	OSA	SEA		5996	3667	6566	8.62	9.62	74	4	67	20	67
NYC	OSL			3192	2610	3340	3.35	3.35	47	2	67	4	67
NYC	PAR			3147	2382	3215	3.39	3.39	48	28	63	42	66
NYC	ROM			3704	2548	3739	4.18	4.18	51	14	67	20	67
NYC	SIN	SEA	TYO	8276	5697	9143	11.24	13.24	69	6	68	6	68
NYC	SJU			1386	870	1391	1.75	1.75	52	4	67	56	65
NYC	SNN			2668	2132	2722	2.76	2.76	46	6	67	10	67

				Distance (n.m.)			Time (hours)			500 Units		1000 Units	
Origin	Dest	Via	Via	GC	Cruise	Path	Block	Trip	Percent subsonic	Daily Departures	Load Factor	Daily Departures	Load Factor
NYC	STO			3395	2600	3548	3.75	3.75	50	4	67	6	67
NYC	TLV	LON		4920	3331	5113	6.02	7.02	66	4	67	12	68
NYC	TYO	SEA		5844	3397	6243	8.35	9.35	74	4	67	36	65
NYC	VIE			3671	2359	3779	4.49	4.49	55	4	67	8	66
NYC	WAW			3694	3032	3840	3.78	3.78	46	2	67	2	67
OSA	SEA			4344	3667	4468	4.18	4.18	44	12	65	14	63
OSA	SFO			4670	3965	4756	4.35	4.35	43	16	62	18	62
OSA	SIN			2668	2183	2797	2.84	2.84	47	26	64	46	67
OSA	SYD			4217	3684	4428	4.08	4.08	44	10	67	12	66
OSA	YVR			4260	3503	4393	4.24	4.24	45	6	67	8	67
PAR	PHL			3228	2550	3264	3.28	3.28	46	2	67	2	67
PAR	PPT	MIA		8478	6360	8795	8.91	9.91	51	4	67	4	67
PAR	RIO	DKR		4956	4046	5400	5.70	6.70	62	8	67	16	67
PAR	SFO			4835	2583	4988	6.50	6.50	62	2	67	4	63
PAR	TYO	GDX		5239	3669	5716	6.74	7.74	68	4	67	16	67
PAR	WAS			3343	2448	3404	3.67	3.67	49	8	67	12	67
PAR	YMQ			2984	2323	3316	3.65	3.65	55	10	61	18	66
PAR	YYZ			3248	2417	3459	3.81	3.81	53	4	67	8	67
PEK	SIN			2422	2290	2919	2.94	2.94	53	2	67	6	63
PER	TYO			4287	2869	4287	4.82	4.82	51	4	64	4	67
PPT	SYD			3301	2689	3303	3.18	3.18	43	24	64	32	65
PPT	TYO	GUM		5096	4439	5664	5.68	6.68	60	4	67	8	67
RIO	TYO	ACA	LAX	10000	7361	10879	12.20	14.20	62	6	67	12	65
ROM	WAS			3901	2592	3924	4.48	4.48	52	2	62	2	67
ROM	YYZ			3823	2461	4010	4.80	4.80	57	2	67	4	64
SEA	SEL			4503	3774	4602	4.30	4.30	44	2	66	10	67
SEA	TPE	TYO		5264	4058	5332	5.52	6.52	57	4	67	4	67
SEA	TYO			4131	3397	4145	3.90	3.90	43	16	65	18	60
SEL	SFO			4887	4080	4904	4.48	4.48	42	4	67	8	67
SEL	SIN			2511	1976	2571	2.66	2.66	47	6	67	12	67
SFO	SYD	HNL		6448	5233	6501	6.31	7.31	53	16	68	20	68

				Distance (n.m.)			Time (hours)			500 Units		1000 Units	
Origin	Dest	Via	Via	GC	Cruise	Path	Block	Trip	Percent subsonic	Daily Departures	Load Factor	Daily Departures	Load Factor
SFO	TPE	TYO		5607	4367	5628	5.70	6.70	55	16	68	20	68
SFO	TYO			4439	3706	4441	4.08	4.08	42	26	62	28	65
SIN	SYD			3400	3603	4300	3.94	3.94	52	30	65	46	66
SIN	TPE			1740	1151	1741	2.08	2.08	51	14	66	66	65
SIN	TYO			2893	2300	2900	2.89	2.89	45	56	66	88	65
SYD	TPE			3931	3597	4314	3.97	3.97	46	2	67	2	67
SYD	TYO			4226	3668	4383	4.02	4.02	43	22	62	24	66
TPE	YVR	TYO		5176	3893	5257	5.58	6.58	59	12	67	16	67
TYO	YVR			4050	3233	4070	3.97	3.97	45	12	64	16	60
ACA	LAX			1439	1183	1720	2.00	2.00	58			8	57
AKL	LON	GUM	GDX	9909	7442	10273	11.00	13.00	58			6	61
AKL	MEL			1423	800	1424	1.90	1.90	55			32	65
AKL	NAN			1163	638	1164	1.60	1.60	55			4	66
AKL	SYD			1164	648	1166	1.59	1.59	55			100	66
AMS	BAH			2576	930	2914	4.63	4.63	79			2	66
AMS	BOS			2993	2215	3132	3.44	3.44	51			2	67
AMS	CAI			1772	791	1836	2.70	2.70	65			2	67
AMS	RIO	DKR		5158	4090	5603	6.03	7.03	63			4	67
AMS	SIN	BAH		5669	3431	6577	8.73	9.73	79			4	68
AMS	TLV			1787	948	1946	2.72	2.72	65			4	67
AMS	TYO	GDX		5028	3543	5503	6.49	7.49	69			4	67
AMS	WAS			3349	2272	3418	3.91	3.91	53			2	67
AMS	YYC			3868	2718	4154	4.76	4.76	56			2	67
ANC	KHV			2536	2548	3614	3.95	3.95	69			2	67
ANC	SEA			1254	761	1362	1.83	1.83	59			32	64
ANC	TYO			2975	2166	3079	3.40	3.40	51			2	67
ATL	CCS			1683	1066	1788	2.27	2.27	57			2	67
ATL	HNL			3902	1642	3904	5.60	5.60	65			2	67
ATL	LIM			2771	1715	3085	3.65	3.65	58			2	67
ATL	SJU			1339	676	1385	1.98	1.98	61			14	62

				Distance (n.m.)			Time (hours)			500 Units		1000 Units	
Origin	Dest	Via	Via	GC	Cruise	Path	Block	Trip	Percent subsonic	Daily Departures	Load Factor	Daily Departures	Load Factor
ATL	TYO	SEA		5935	3397	6037	7.95	8.95	70			4	67
BAH	CAN			3382	3476	4772	4.99	4.99	66			2	67
BAH	GVA			2422	936	2672	4.16	4.16	75			4	66
BAH	LON			2748	928	3029	4.85	4.85	78			22	65
BAH	MIL			2307	1118	2676	3.95	3.95	75			2	64
BAH	PAR			2602	932	2860	4.53	4.53	77			6	61
BER	CAI			1563	793	1756	2.55	2.55	68			2	67
BER	RIO	DKR		5396	4087	5866	6.54	7.54	64			4	67
BER	TLV			1549	950	1866	2.56	2.56	69			2	67
BER	YYZ			3496	2225	3830	4.75	4.75	61			2	67
BKK	BOM			1623	1698	2342	2.56	2.56	66			6	67
BKK	CAI			3915	2191	4461	5.98	5.98	69			2	67
BKK	CMB			1287	642	1286	1.83	1.83	58			2	67
BKK	DHA			2918	2238	3479	4.07	4.07	62			2	67
BKK	JKT			1259	724	1282	1.72	1.72	55			6	67
BKK	KHI			1998	2067	2755	2.90	2.90	63			10	67
BKK	MNL			1186	959	1536	1.92	1.92	65			24	66
BKK	SYD	POM		4070	3958	5160	5.34	6.34	71			12	67
BOG	FRA			4902	3328	4931	5.47	5.47	51			2	62
BOG	MIA			1314	506	1314	2.05	2.05	64			8	67
BOG	NYC			2156	1290	2168	2.73	2.73	55			4	67
BOM	FRA			3545	1151	4093	6.21	6.21	79			2	67
BOM	GVA			3623	1155	4045	6.11	6.11	76			2	67
BOM	HKG			2320	2976	3625	3.44	3.44	65			6	67
BOM	LON			3892	1124	4402	6.81	6.81	79			10	67
BOM	PAR			3774	1140	4232	6.48	6.48	78			2	67
BOS	BRU			3014	2291	3124	3.33	3.33	49			2	67
BOS	MIA			1094	610	1163	1.63	1.63	59			26	64
BOS	ROM			3544	2418	3620	4.11	4.11	52			2	67
BOS	SJU			1454	911	1458	1.83	1.83	52			4	67
BRU	DKR			2416	1937	2707	2.97	2.97	54			2	67

				Distance (n.m.)			Time (hours)			500 Units		1000 Units	
Origin	Dest	Via	Via	GC	Cruise	Path	Block	Trip	Percent subsonic	Daily Departures	Load Factor	Daily Departures	Load Factor
BRU	TLV			1754	949	1891	2.61	2.61	63			2	65
BRU	TYO	GDX		5103	3592	5586	6.59	7.59	68			4	67
BUE	ROM	DKR		6019	4468	6555	7.06	8.06	62			4	67
CAI	FRA			1575	795	1642	2.33	2.33	62			2	67
CAI	GVA			1522	796	1594	2.23	2.23	61			2	60
CAI	LON			1904	788	1951	2.92	2.92	66			4	67
CAI	MAD			1806	1116	1816	2.27	2.27	53			2	67
CAI	PAR			1731	792	1782	2.60	2.60	64			6	67
CAI	ROM			1159	780	1348	1.78	1.78	61			4	67
CAN	JKT			1799	1237	1811	2.11	2.11	50			2	67
CAN	SIN			1416	871	1426	1.82	1.82	53			2	67
CCS	CHI			2180	1048	2206	3.09	3.09	62			2	67
CCS	LAX			3139	2464	3952	4.69	4.69	67			2	67
CCS	MIA			1183	663	1184	1.61	1.61	55			20	66
CHI	CPH			3697	2734	4110	4.65	4.65	57			2	67
CHI	MIL			3916	2271	4125	5.25	5.25	61			2	67
CHI	SJU			1795	655	1801	2.80	2.80	66			6	67
CHI	STO			3698	2487	4177	5.09	5.09	62			2	67
CHI	WAW			4056	2915	4469	5.11	5.11	57			2	67
CMB	DHA			2046	1008	2112	2.96	2.96	63			4	67
CMB	FRA			4352	1758	4760	6.70	6.70	70			2	67
CMB	SIN			1479	956	1537	1.93	1.93	54			6	65
DEL	SIN			2240	1077	2271	3.18	3.18	62			8	66
DEL	TYO			3188	3464	4854	5.16	5.16	73			2	67
DFW	SJU			1872	1252	2001	2.45	2.45	56			2	67
DFW	TYO	SEA		5569	3397	5585	7.08	8.08	67			4	67
DHA	FRA			2379	936	2696	4.17	4.17	77			2	67
DHA	LON			2731	929	3005	4.76	4.76	77			8	64
DHA	NYC	LIS		5715	3538	5967	7.40	8.40	68			4	65
DHA	PAR			2584	933	2835	4.44	4.44	76			2	67
DKR	GVA			2231	1878	2700	3.03	3.03	59			2	62

				Distance (n.m.)			Time (hours)			500 Units		1000 Units	
Origin	Dest	Via	Via	GC	Cruise	Path	Block	Trip	Percent subsonic	Daily Departures	Load Factor	Daily Departures	Load Factor
DKR	LIS			1508	1129	1660	1.95	1.95	54			2	67
DKR	PAR			2280	1851	2583	2.83	2.83	54			4	64
DTW	LON			3261	2278	3477	4.02	4.02	55			2	67
DTW	OSA	SEA		5712	3667	6138	7.80	8.80	71			4	67
DTW	TYO	SEA		5542	3397	5815	7.52	8.52	71			8	67
FDF	YYZ			2014	1245	2202	2.85	2.85	61			2	67
FRA	JKT	BAH		6001	3450	6581	8.71	9.71	75			4	67
FRA	LAX	YYC		5030	2776	5393	7.46	8.46	77			4	68
FRA	MEX	MIA		5153	3631	5346	6.07	7.07	63			4	68
FRA	RIO	DKR		5163	4035	5655	6.20	7.20	64			4	67
FRA	SIN	BAH		5543	3435	6383	8.35	9.35	78			4	67
FRA	SJU			3970	2909	3974	4.18	4.18	48			2	64
FRA	SYD	GDX	GUM	8901	7255	10000	10.70	12.70	62			6	63
FRA	TLV			1594	953	1752	2.34	2.34	62			6	65
FRA	TYO	GDX		5054	3592	5700	6.81	7.81	71			4	67
GUM	JKT			2549	2107	2702	2.75	2.75	48			2	59
GUM	MNL			1385	849	1385	1.77	1.77	53			12	66
GUM	OSA			1375	820	1374	1.78	1.78	53			18	64
GUM	SEL			1734	1388	1954	2.20	2.20	54			4	67
GVA	SIN	BAH		5663	3437	6335	8.26	9.26	76			4	68
GVA	TLV			1575	954	1704	2.25	2.25	60			6	66
GVA	TYO	GDX		5295	3566	5871	7.16	8.16	71			4	67
GVA	YYZ			3455	2386	3663	4.24	4.24	55			2	67
HAV	MAD			4027	3179	4027	3.95	3.95	45			2	67
HKG	LON	GDX		5205	5419	7549	8.10	9.10	81			16	60
HKG	OSA			1341	1096	1665	2.00	2.00	61			36	65
HKG	PAR	GDX		5183	5569	7705	8.21	9.21	82			4	67
HKG	SEL			1122	870	1421	1.81	1.81	64			24	61
HNL	NAN			2756	2161	2756	2.79	2.79	45			2	67
HNL	NYC			4320	1473	4321	6.59	6.59	70			2	67
HNL	YYZ			4029	1482	4032	6.04	6.04	68			2	67

				Distance (n.m.)			Time (hours)			500 Units		1000 Units	
Origin	Dest	Via	Via	GC	Cruise	Path	Block	Trip	Percent subsonic	Daily Departures	Load Factor	Daily Departures	Load Factor
HOU	SJU			1719	1211	1773	2.07	2.07	51			2	67
HOU	TYO	SEA		5780	3397	5789	7.47	8.47	68			4	67
JKT	LAX	TYO		7789	6516	8011	7.61	8.61	47			4	68
JKT	MEL			2802	3343	4377	4.41	4.41	70			2	67
JKT	MNL			1499	1162	1710	2.01	2.01	56			2	67
JKT	PEK			2824	2579	3231	3.18	3.18	50			2	67
JNB	LON	DKR		4896	4727	6671	7.27	8.27	78			12	65
JNB	MRU			1654	1015	1759	2.28	2.28	58			2	64
JNB	NYC	DKR		6923	5483	7415	7.76	8.76	54			4	61
KHI	SIN			2554	2332	2958	2.96	2.96	51			2	67
LAX	MEX			1348	765	1596	2.27	2.27	69			34	66
LAX	RIO	ACA		5470	3502	6153	7.77	8.77	74			4	67
LIM	MEX			2289	1549	2298	2.66	2.66	51			2	67
LIM	PTY			1266	837	1419	1.85	1.85	59			2	67
LON	MNL	GDX		5809	5193	7328	7.96	8.96	71			4	67
LON	OSA	GDX		5128	3842	5916	6.92	7.92	71			16	67
LON	SIN	BAH		5868	3428	6692	8.95	9.95	79			20	68
LON	TLV			1936	945	2061	2.94	2.94	65			10	65
LON	YHZ			2473	1778	2510	2.79	2.79	50			2	67
MAD	TLV			1912	1274	1925	2.28	2.28	51			2	67
MAD	YMQ			3004	2269	3224	3.55	3.55	53			2	67
MEL	NAN			2086	1275	2087	2.59	2.59	54			2	67
MEL	PER			1456	1074	1776	2.24	2.24	64			24	65
MEX	MIA			1106	491	1107	1.67	1.67	60			22	61
MEX	NYC			1816	1736	2385	2.60	2.60	61			12	61
MEX	PTY			1297	691	1464	2.11	2.11	66			2	67
MEX	SFO			1634	1037	1893	2.51	2.51	65			20	64
MEX	WAS			1620	1640	2353	2.65	2.65	69			2	67
MIL	RIO	DKR		4986	3305	5338	6.48	7.48	69			4	67
MNL	OSA			1444	810	1445	1.93	1.93	55			12	67
MNL	PEK			1550	986	1751	2.30	2.30	62			2	67

				Distance (n.m.)			Time (hours)			500 Units		1000 Units	
Origin	Dest	Via	Via	GC	Cruise	Path	Block	Trip	Percent subsonic	Daily Departures	Load Factor	Daily Departures	Load Factor
MNL	SEL			1415	692	1432	2.05	2.05	60			16	61
MNL	SIN			1284	754	1282	1.69	1.69	53			16	67
MRU	SIN			3013	2219	3018	3.21	3.21	48			2	67
MUC	TLV			1433	956	1613	2.07	2.07	60			2	67
MUC	YYZ			3583	2481	3820	4.42	4.42	56			2	67
NAN	SYD			1710	1172	1711	2.00	2.00	49			6	67
NYC	PTY			1924	1374	1928	2.17	2.17	48			2	67
NYC	RIO	SJU		4170	3663	5196	5.76	6.76	74			8	67
OSA	PAR	GDX		5179	3992	6072	7.03	8.03	71			4	67
PAR	SIN	BAH		5783	3432	6523	8.62	9.62	77			4	68
PAR	STL			3808	2461	3961	4.71	4.71	56			2	67
PAR	TLV			1773	949	1891	2.61	2.61	63			14	67
PER	SIN			2112	1492	2298	2.73	2.73	56			6	67
PER	SYD			1768	2106	2688	2.72	2.72	65			54	65
RIO	ROM	DKR		4949	3388	5406	6.21	7.21	67			4	67
ROM	YMQ			3557	2407	3861	4.59	4.59	58			2	67
SEL	YVR			4411	3610	4527	4.36	4.36	45			2	67
SFO	SIN	TYO		7331	6006	7341	6.97	7.97	46			4	68
SHA	SIN			2044	1728	2298	2.44	2.44	52			2	67
SJU	WAS			1362	744	1368	1.86	1.86	56			14	64
SJU	YYZ			1659	1051	1942	2.59	2.59	66			4	67
SYD	YVR	HNL		6745	5455	6768	6.55	7.55	47			4	68
TYO	WAS	SEA		5851	3397	6142	8.15	9.15	72			4	67
TYO	YYZ	YVR		5557	3233	5876	7.84	8.84	74			4	67
										2174		4836	

Appendix D. HSCT Routing Table

The following table provides a list of the city paris which make up the universal HSCT route system. It also includes the waypoints (latitude, longitude) between each city-pair used to avoid supersonic flight over land. Great circle routes were flown between city pairs unless waypoint routing was necessary. If waypoints were used, great circle routes were flown between the waypoints.

Origin	Dest.	Waypoint 1 Lat.	Waypoint 1 Long.	Waypoint 2 Lat.	Waypoint 2 Long.	Waypoint 3 Lat.	Waypoint 3 Long.	Waypoint 4 Lat.	Waypoint 4 Long.	Waypoint 5 Lat.	Waypoint 5 Long.	Waypoint 6 Lat.	Waypoint 6 Long.	Waypoint 7 Lat.	Waypoint 7 Long.
ACA	LAX	1500N	10500W	2500N	11500W	3000N	11800W								
ACA	RIO	0500S	06300W	2000S	07500W										
AKL	GUM														
AKL	HNL														
AKL	JKT	2000S	15500E	1000S	14200E	0700S	12000E								
AKL	MEL														
AKL	NAN														
AKL	OSA														
AKL	PER	4500S	15000E	3500S	11300E										
AKL	POM	2000S	15500E												
AKL	PPT														
AKL	SIN	2000S	15500E	1000S	14200E	0700S	12000E	0307S	10900E						
AKL	SYD														
AKL	TYO														
AMS	ATL	5100N	00900W	3226N	07823W										
AMS	BAH	4530N	01221E	4000N	01900E	3720N	01947E	3425N	02400E	3110N	03325E	2845N	03440E		
AMS	BOS	5100N	00900W	4700N	05000W	4108N	06700W								
AMS	CAI	4530N	01221E	4000N	01900E	3720N	01947E	3425N	02400E						
AMS	CCS	5100N	00900W												
AMS	CHI	5100N	00900W	4700N	05000W	4108N	06700W								
AMS	DFW	5100N	00900W	3226N	07823W										
AMS	DKR	5100N	00900W	4200N	01700W										
AMS	DTW	5100N	00900W	4700N	05000W	4108N	06700W								
AMS	GDX	6230N	00300E	7200N	02500E	7200N	13230E								
AMS	MIA	5100N	00900W												
AMS	MSP	6000N	00500W	5800N	04500W	6100N	06500W	6200N	07000W	6300N	07500W	6230N	06000W		
AMS	NYC	5100N	00900W	4700N	05000W	4108N	06700W								
AMS	TLV	4530N	01221E	4000N	01900E	3720N	01947E	3425N	02400E						
AMS	WAS	5100N	00900W	4700N	05000W										
AMS	YMQ	5100N	00900W	4700N	05000W	4108N	06700W								
AMS	YVR	6000N	00500W	5800N	04500W	6100N	06500W	6200N	07000W	6300N	07500W	6230N	06000W		
AMS	YYC	6000N	00500W	5800N	04500W	6100N	06500W	6200N	07000W	6300N	07500W	6230N	06000W		
AMS	YYZ	5100N	00900W	4700N	05000W	4108N	06700W								
ANC	HKG	5730N	16500W	3500N	14200E	2000N	12500E								
ANC	KHV	5730N	16500W	3700N	14700E										
ANC	PAR	8500N	01000W	6230N	00300E	5700N	00300E								
ANC	SEA	5000N	13500W												
ANC	TPE	5730N	16500W	3330N	14000E										

Origin	Dest.	Waypoint 1 Lat.	Waypoint 1 Long.	Waypoint 2 Lat.	Waypoint 2 Long.	Waypoint 3 Lat.	Waypoint 3 Long.	Waypoint 4 Lat.	Waypoint 4 Long.	Waypoint 5 Lat.	Waypoint 5 Long.	Waypoint 6 Lat.	Waypoint 6 Long.	Waypoint 7 Lat.	Waypoint 7 Long.
ANC	TYO	5730N	16500W	3700N	14700E										
ATH	NYC	4450N	00043W	4600N	00800W	4600N	05000W	4106N	06700W						
ATL	BER	3226N	07823W	4800N	00600W										
ATL	CCS	3226N	07823W	1730N	06800W										
ATL	FRA	3226N	07823W	4600N	00600W										
ATL	GVA	3226N	07823W	4600N	00600W										
ATL	HNL														
ATL	LIM	2600N	07600W	0500S	08300W										
ATL	LON	3226N	07823W	5100N	00900W										
ATL	MAD	3226N	07823W												
ATL	MUC	3226N	07823W	4600N	00600W										
ATL	PAR	3226N	07823W	4800N	00600W										
ATL	SEA														
ATL	SJU	3226N	07823W												
ATL	SNN	3226N	07823W	4700N	05000W										
BAH	BKK	1930N	05740E	0500N	08000E										
BAH	CAN	1930N	05740E	0500N	08000E	0610N	09700E	0800N	10800E						
BAH	CMB	1930N	05740E	0730N	07500E										
BAH	GVA	2845N	03440E	3110N	03325E	3425N	02400E	3720N	01947E	4000N	01900E	4530N	01221E		
BAH	HKG	1930N	05740E	0500N	08000E	0610N	09700E	0800N	10800E						
BAH	JKT	1930N	05740E	0500N	08000E										
BAH	LON	2845N	03440E	3110N	03325E	3425N	02400E	3720N	01947E	4000N	01900E	4530N	01221E		
BAH	MIL	2845N	03440E	3110N	03325E	3425N	02400E	3700N	01200E						
BAH	MNL	1930N	05740E	0500N	08000E	0610N	09700E	0800N	10800E						
BAH	PAR	2845N	03440E	3110N	03325E	3425N	02400E	3720N	01947E	4000N	01900E	4530N	01221E		
BAH	SIN	1930N	05740E	0500N	08000E	0610N	09700E	0200N	10200E						
BER	BOS	5100N	00900W	4700N	05000W	4106N	06700W								
BER	CAI	4530N	01221E	4000N	01900E	3720N	01947E	3425N	02400E						
BER	CHI	5100N	00900W	4700N	05000W	4106N	06700W								
BER	DFW	5100N	00900W	3226N	07823W										
BER	DKR	4200N	01700W	2000N	02000W										
BER	MIA	4800N	00600W												
BER	NYC	5100N	00900W	4700N	05000W	4106N	06700W								
BER	TLV	4530N	01221E	4000N	01900E	3720N	01947E	3425N	02400E						
BER	WAS	5100N	00900W	4700N	05000W	4106N	06700W								
BER	YVR	6000N	00500W	5800N	04500W	6100N	06500W	6200N	07000W	6300N	07500W	6230N	08000W		
BER	YYZ	5100N	00900W	4700N	05000W	4106N	06700W								
BKK	BOM	0500N	08000E	1000N	07500E	1730N	07200E								

Origin	Dest.	Waypoint 1 Lat.	Waypoint 1 Long.	Waypoint 2 Lat.	Waypoint 2 Long.	Waypoint 3 Lat.	Waypoint 3 Long.	Waypoint 4 Lat.	Waypoint 4 Long.	Waypoint 5 Lat.	Waypoint 5 Long.	Waypoint 6 Lat.	Waypoint 6 Long.	Waypoint 7 Lat.	Waypoint 7 Long.
BKK	CAI	0500N	08000E	1930N	05740E	2845N	03440E								
BKK	CMB														
BKK	DHA	0500N	08000E	1930N	05740E										
BKK	JKT	0700N	10500E												
BKK	KHI	0500N	08000E	1000N	07500E	1730N	07200E								
BKK	MNL	0700N	10500E	0800N	10800E										
BKK	OSA	0700N	10500E	0800N	10800E	3300N	13700E								
BKK	PER	0400N	10400E	1000S	11000E	3000S	11000E								
BKK	POM	0307S	10900E	0700S	12000E	1000S	14200E								
BKK	SEL	0700N	10500E	0800N	10800E	3000N	12500E	3500N	12500E						
BKK	TYO	0700N	10500E	0800N	10800E	3300N	13700E								
BOG	FRA	4200N	01700W												
BOG	MAD														
BOG	MIA														
BOG	NYC	2600N	07600W												
BOM	FRA	1930N	05740E	2845N	03440E	3110N	03325E	3425N	02400E	3720N	01947E	4000N	01900E	4530N	01221E
BOM	GVA	1930N	05740E	2845N	03440E	3110N	03325E	3425N	02400E	3720N	01947E	4000N	01900E	4530N	01221E
BOM	HKG	1730N	07200E	1000N	07500E	0500N	08000E	0610N	09700E	0800N	10800E				
BOM	LON	1930N	05740E	2845N	03440E	3110N	03325E	3425N	02400E	3720N	01947E	4000N	01900E	4530N	01221E
BOM	PAR	1930N	05740E	2845N	03440E	3110N	03325E	3425N	02400E	3720N	01947E	4000N	01900E	4530N	01221E
BOM	SIN	1730N	07200E	1000N	07500E	0500N	08000E	0610N	09700E	0200N	10200E				
BOS	BRU	4108N	06700W	4700N	05000W	5100N	00900W								
BOS	FRA	4108N	06700W	4700N	05000W	5100N	00900W								
BOS	GVA	4108N	06700W	4800N	00600W										
BOS	LON	4108N	06700W	4700N	05000W	5100N	00900W								
BOS	MIA	3820N	06957W												
BOS	PAR	4108N	06700W	4800N	00600W										
BOS	ROM	4108N	06700W												
BOS	SJU														
BOS	SNN	4108N	06700W	4700N	05000W										
BRU	CHI	5100N	00900W	4700N	05000W	4108N	06700W								
BRU	DKR	4200N	01700W	2000N	02000W										
BRU	GDX	6230N	00300E	7200N	02500E	7200N	13230E								
BRU	NYC	5100N	00900W	4700N	05000W	4108N	06700W								
BRU	TLV	4530N	01221E	4000N	01900E	3720N	01947E	3425N	02400E						
BRU	WAS	5100N	00900W	4700N	05000W	4108N	06700W								
BRU	YMQ	5100N	00900W	4700N	05000W	4108N	06700W								
BUE	DKR	3600S	05200W	2000S	03500W										

Origin	Dest.	Waypoint 1		Waypoint 2		Waypoint 3		Waypoint 4		Waypoint 5		Waypoint 6		Waypoint 7	
		Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.
CAI	FRA	3425N	02400E	3720N	01947E	4000N	01900E	4530N	01221E						
CAI	GVA	3425N	02400E	3720N	01947E	4000N	01900E	4530N	01221E						
CAI	LON	3425N	02400E	3720N	01947E	4000N	01900E	4530N	01221E						
CAI	MAD	3425N	02400E	3700N	01200E										
CAI	NYC	3425N	02400E	4108N	06700W										
CAI	PAR	3425N	02400E	3720N	01947E	4000N	01900E	4530N	01221E						
CAI	ROM	3425N	02400E	3700N	01200E										
CAN	JKT	0800N	10800E												
CAN	SIN	0800N	10800E												
CAN	TYO	2000N	12500E												
CCS	CHI	1730N	06800W	3226N	07623W										
CCS	FRA	4200N	01700W												
CCS	LAX	1130N	07000W	1036N	07928W	0847N	07934W	0630N	08000W	1500N	10500W	2500N	11500W	3000N	11800W
CCS	LIS														
CCS	LON	4800N	00600W												
CCS	MAD														
CCS	MIA														
CCS	MIL														
CCS	NYC	1730N	06800W	3820N	06957W										
CCS	PAR	4800N	00600W												
CCS	ROM														
CHI	CPH	4108N	06700W	4700N	05000W	6000N	00500W								
CHI	FRA	4108N	06700W	4700N	05000W	5100N	00900W								
CHI	GVA	4108N	06700W	4800N	00600W										
CHI	HNL														
CHI	LON	4108N	06700W	4700N	05000W	5100N	00900W								
CHI	MIL	4108N	06700W												
CHI	MUC	4108N	06700W	4700N	05000W	5100N	00900W								
CHI	PAR	4108N	06700W	4800N	00600W										
CHI	ROM	4108N	06700W												
CHI	SEA														
CHI	SJU														
CHI	STO	4108N	06700W	4700N	05000W										
CHI	WAW	4108N	06700W	4700N	05000W	6000N	00500W								
CMB	DHA	0730N	07500E	1930N	05740E										
CMB	FRA	0730N	07500E	2845N	03440E	3110N	03325E	3425N	02400E	3720N	01947E	4000N	01900E	4530N	01221E
CMB	PAR	0730N	07500E	2845N	03440E	3110N	03325E	3425N	02400E	3720N	01947E	4000N	01900E	4530N	01221E
CMB	SIN	0610N	09700E	0200N	10200E										

Origin	Dest.	Waypoint 1 Lat.	Waypoint 1 Long.	Waypoint 2 Lat.	Waypoint 2 Long.	Waypoint 3 Lat.	Waypoint 3 Long.	Waypoint 4 Lat.	Waypoint 4 Long.	Waypoint 5 Lat.	Waypoint 5 Long.	Waypoint 6 Lat.	Waypoint 6 Long.	Waypoint 7 Lat.	Waypoint 7 Long.
CPH	NYC	6000N	00500W	4700N	05000W	4106N	06700W								
CPH	SEA	6000N	00500W	5800N	04500W	6100N	06500W	6200N	07000W	6300N	07500W	6230N	08000W		
CVG	FRA	4106N	06700W	4700N	05000W	5100N	00900W								
CVG	LON	4106N	06700W	4700N	05000W	5100N	00900W								
DEL	SIN	0610N	09700E	0200N	10200E										
DEL	TYO	0610N	09700E	0800N	10800E	3300N	13700E								
DFW	FRA	3226N	07823W	5100N	00900W										
DFW	HNL														
DFW	LON	3226N	07823W	5100N	00900W										
DFW	MAD	3226N	07823W												
DFW	PAR	3226N	07823W	4800N	00600W										
DFW	SEA														
DFW	SJU	2900N	09500W	2400N	08230W	2350N	08000W	2350N	07500W						
DHA	FRA	2845N	03440E	3110N	03325E	3425N	02400E	3720N	01947E	4000N	01900E	4530N	01221E		
DHA	JKT	1930N	05740E	0500N	08000E										
DHA	LIS	3110N	03325E	3425N	02400E	3730N	01200E	3830N	00730E						
DHA	LON	2845N	03440E	3110N	03325E	3425N	02400E	3720N	01947E	4000N	01900E	4530N	01221E		
DHA	MNL	1930N	05740E	0500N	08000E	0610N	09700E	0800N	10800E						
DHA	PAR	2845N	03440E	3110N	03325E	3425N	02400E	3720N	01947E	4000N	01900E	4530N	01221E		
DHA	SIN	1930N	05740E	0500N	08000E	0610N	09700E	0200N	10200E						
DKR	GVA	2000N	02000W	4200N	01700W										
DKR	HAV														
DKR	LIS	2000N	02000W	2700N	02000W										
DKR	LON	2000N	02000W	4200N	01700W										
DKR	MAD	2000N	02000W	3000N	01800W	3701N	00756W								
DKR	NYC														
DKR	PAR	2000N	02000W	4200N	01700W										
DKR	RIO	2000S	03500W												
DKR	ROM	2000N	02000W	3000N	01800W	3701N	00756W								
DTW	FRA	4106N	06700W	4700N	05000W	5100N	00900W								
DTW	LON	4106N	06700W	4700N	05000W	5100N	00900W								
DTW	PAR	4106N	06700W	4700N	05000W	5100N	00900W								
DTW	SEA														
FDF	FRA	4800N	00600W												
FDF	LON	5100N	00900W												
FDF	MAD														
FDF	PAR	4800N	00600W												
FDF	YYZ	4106N	06700W												

Origin	Dest.	Waypoint 1		Waypoint 2		Waypoint 3		Waypoint 4		Waypoint 5		Waypoint 6		Waypoint 7	
		Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.
FRA	BAH	4530N	01221E	4000N	01900E	3720N	01947E	3425N	02400E	3110N	03325E	2845N	03440E		
FRA	DKR	4200N	01700W	2000N	02000W										
FRA	GDX	5219N	00447E	6230N	00300E	7200N	02500E	7200N	13230E						
FRA	HOU	4800N	00600W	3226N	07823W										
FRA	MIA	4800N	00600W												
FRA	NYC	5100N	00900W	4700N	05000W	4108N	06700W								
FRA	PHL	5100N	00900W	4700N	05000W	4108N	06700W								
FRA	SJU	4800N	00600W												
FRA	TLV	4530N	01221E	4000N	01900E	3720N	01947E	3425N	02400E						
FRA	WAS	5100N	00900W	4700N	05000W	4108N	06700W								
FRA	YMQ	5100N	00900W	4700N	05000W	4108N	06700W								
FRA	YVR	6000N	00500W	5800N	04500W	6100N	06500W	6200N	07000W	6300N	07500W	6230N	08000W		
FRA	YYC	6000N	00500W	5800N	04500W	6100N	06500W	6200N	07000W	6300N	07500W	6230N	08000W		
FRA	YYZ	5100N	00900W	4700N	05000W	4108N	06700W								
GDX	GUM														
GDX	LON	7200N	13230E	7200N	02500E	6230N	00300E								
GDX	MNL	3700N	14700E	3500N	14200E										
GDX	OSA	3700N	14700E	3400N	14100E										
GDX	PAR	7200N	13230E	7200N	02500E	6230N	00300E								
GDX	TYO	3700N	14700E												
GUM	GDX														
GUM	HNL														
GUM	JKT	0300N	12200E	0000N	11630E	0500S	11700E								
GUM	MNL														
GUM	OSA														
GUM	SEL	3000N	12500E	3500N	12500E										
GUM	SYD	0500S	15400E	2000S	15500E	3230S	15400E								
GUM	TYO														
GVA	BAH	4530N	01221E	4000N	01900E	3720N	01947E	3425N	02400E	3110N	03325E	2845N	03440E		
GVA	GDX	5219N	00447E	6230N	00300E	7200N	02500E	7200N	13230E						
GVA	NYC	4800N	00600W	4108N	06700W										
GVA	TLV	4530N	01221E	4000N	01900E	3720N	01947E	3425N	02400E						
GVA	YMQ	4700N	05000W	4108N	06700W										
GVA	YYZ	5100N	00900W	4700N	05000W	4108N	06700W								
HAV	MAD														
HEL	NYC	4700N	05000W	4108N	06700W										
HKG	GDX	2000N	12500E	3500N	14200E	3700N	14700E								
HKG	HNL	2200N	12230E												

Origin	Dest.	Waypoint 1		Waypoint 2		Waypoint 3		Waypoint 4		Waypoint 5		Waypoint 6		Waypoint 7	
		Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.
HKG	JKT	0600N	10800E												
HKG	MEL	2000N	12200E	0330S	14700E	1000S	15200E	2000S	15500E	2500S	15500E	3230S	15400E		
HKG	OSA	2000N	12500E												
HKG	PER	0600N	10800E	1000S	11000E	3000S	11000E								
HKG	SEL	2200N	12230E												
HKG	SIN	0600N	10800E												
HKG	SYD	2000N	12200E	0330S	14700E	1000S	15200E	2000S	15500E	2500S	15500E	3230S	15400E		
HKG	TYO	2000N	12500E												
HNL	GUM														
HNL	HOU														
HNL	LAX														
HNL	MEL	2500S	16500E												
HNL	MNL														
HNL	NAN														
HNL	NYC														
HNL	OSA	3400N	14100E												
HNL	PPT														
HNL	SEA														
HNL	SEL	3000N	13000E	3500N	12500E										
HNL	SFO														
HNL	STL														
HNL	SYD	2500S	16500E												
HNL	TPE														
HNL	TYO														
HNL	YVR														
HNL	YYZ														
HOU	LON	3226N	07823W	5100N	00900W										
HOU	PAR	3226N	07823W	4800N	00600W										
HOU	SEA														
HOU	SJU	2400N	08230W	2350N	08000W	2350N	07500W								
JKT	MEL	0700S	12000E	1000S	14200E	2000S	15500E	2500S	15500E	3230S	15400E				
JKT	MNL	0600N	10800E												
JKT	OSA	0600N	10800E	3300N	13700E										
JKT	PEK	0600N	10800E	3000N	12300E	3800N	12300E	3900N	11800E						
JKT	SEL	0600N	10800E	3000N	12500E	3500N	12500E								
JKT	SYD	0700S	12000E	1000S	14200E	2000S	15500E	2500S	15500E	3230S	15400E				
JKT	TPE	0600N	10800E												
JKT	TYO	0600N	10800E	3300N	13700E										

Origin	Dest.	Waypoint 1 Lat.	Waypoint 1 Long.	Waypoint 2 Lat.	Waypoint 2 Long.	Waypoint 3 Lat.	Waypoint 3 Long.	Waypoint 4 Lat.	Waypoint 4 Long.	Waypoint 5 Lat.	Waypoint 5 Long.	Waypoint 6 Lat.	Waypoint 6 Long.	Waypoint 7 Lat.	Waypoint 7 Long.
JNB	DKR	2600S	01500E	1400N	02100W										
JNB	MRU	2800S	04800E												
JNB	PER														
JNB	RIO														
JNB	SIN	2800S	04800E												
LAX	ACA	3000N	11800W	2500N	11500W	1500N	10500W								
LAX	HNL														
LAX	LON	6230N	06000W	6300N	07500W	6200N	07000W	6100N	06500W	5800N	04500W	5100N	00900W		
LAX	MEX	3000N	11800W	2000N	11000W										
LAX	NAN														
LAX	OSA	3400N	14100E												
LAX	PPT														
LAX	TYO														
LIM	MEX	1500N	09700W												
LIM	MIA	0500S	08300W												
LIM	NYC	0500S	08300W	2500N	07500W										
LIM	PTY	0500S	08300W												
LIS	NYC														
LIS	RIO	3000N	01800W	0730S	03200W	2000S	03500W								
LON	BAH	4530N	01221E	4000N	01900E	3720N	01947E	3425N	02400E	3110N	03325E	2845N	03440E		
LON	DKR	4200N	01700W	2000N	02000W										
LON	GDX	6230N	00300E	7200N	02500E	7200N	13230E								
LON	MIA	5100N	00900W												
LON	MSP	5100N	00900W	5800N	04500W	6100N	06500W	6200N	07000W	6300N	07500W	6230N	08000W		
LON	NYC	5100N	00900W	4700N	05000W	4108N	06700W								
LON	PHL	5100N	00900W	4700N	05000W	4108N	06700W								
LON	SEA	5100N	00900W	5800N	04500W	6100N	06500W	6200N	07000W	6300N	07500W	6230N	08000W		
LON	SFO	5100N	00900W	5800N	04500W	6100N	06500W	6200N	07000W	6300N	07500W	6230N	08000W		
LON	SJU	5100N	00900W												
LON	STL	5100N	00900W	4700N	05000W	4108N	06700W								
LON	TLV	4530N	01221E	4000N	01900E	3720N	01947E	3425N	02400E						
LON	WAS	5100N	00900W	4700N	05000W	4108N	06700W								
LON	YHZ	5100N	00900W	4700N	05000W										
LON	YMQ	5100N	00900W	4700N	05000W	4108N	06700W								
LON	YVR	5100N	00900W	5800N	04500W	6100N	06500W	6200N	07000W	6300N	07500W	6230N	08000W		
LON	YYC	5100N	00900W	5800N	04500W	6100N	06500W	6200N	07000W	6300N	07500W	6230N	08000W		
LON	YYZ	5100N	00900W	4700N	05000W	4108N	06700W								
MAD	MIA														

Origin	Dest.	Waypoint 1 Lat.	Long.	Waypoint 2 Lat.	Long.	Waypoint 3 Lat.	Long.	Waypoint 4 Lat.	Long.	Waypoint 5 Lat.	Long.	Waypoint 6 Lat.	Long.	Waypoint 7 Lat.	Long.
MAD	NYC	4106N	06700W												
MAD	RIO	3701N	00756W	2700N	02000W	2000S	03500W								
MAD	TLV	3700N	01200E	3425N	02400E										
MAD	WAS	4106N	06700W												
MAD	YMQ	4106N	06700W												
MEL	HNL	2500S	16500E												
MEL	NAN														
MEL	OSA	3230S	15400E	2500S	15500E	2000S	15500E	0500S	15400E						
MEL	PER	3500S	11300E												
MEL	PPT														
MEL	SIN	3230S	15400E	2500S	15500E	2000S	15500E	1000S	14200E	0700S	12000E	0307S	10900E		
MEL	TYO	3230S	15400E	2500S	15500E	2000S	15500E	0500S	15400E						
MEX	MIA														
MEX	NYC	2400N	08230W	2350N	08000W	2350N	07500W								
MEX	PTY	1500N	09700W	0730N	08230W										
MEX	SFO	2000N	11000W	3356N	12200W										
MEX	WAS	2400N	08230W	2350N	08000W	2350N	07500W	3800N	07500W						
MIA	MEX														
MIA	MUC	4800N	00600W												
MIA	PAR	4800N	00600W												
MIA	PPT														
MIA	RIO	2600N	07600W	2000N	06000W	0730S	03200W	2000S	03500W						
MIA	ROM														
MIA	SCL	0500S	08300W												
MIL	DKR	3701N	00756W	3000N	01800W	2000N	02000W								
MIL	NYC	4600N	00800W	4106N	06700W										
MIL	WAS	4600N	00800W	4106N	06700W										
MNL	OSA														
MNL	PEK	2000N	12200E	3000N	12300E	3800N	12300E	3900N	11800E						
MNL	SEL	3000N	12500E	3500N	12500E										
MNL	SIN														
MNL	SYD	0330S	14700E	1000S	15200E	2000S	15500E	2500S	15500E	3230S	15400E				
MNL	TYO														
MOW	NYC	6000N	00500W	4700N	05000W	4106N	06700W								
MRU	SIN														
MUC	NYC	5100N	00900W	4700N	05000W	4106N	06700W								
MUC	TLV	4530N	01221E	4000N	01900E	3720N	01947E	3425N	02400E						
MUC	WAS	5100N	00900W	4700N	05000W	4106N	06700W								

Origin	Dest.	Waypoint 1		Waypoint 2		Waypoint 3		Waypoint 4		Waypoint 5		Waypoint 6		Waypoint 7	
		Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.	Lat.	Long.
MUC	YVR	6000N	00500W	5800N	04500W	6100N	06500W	6200N	07000W	6300N	07500W	6230N	08000W		
MUC	YYC	6000N	00500W	5800N	04500W	6100N	06500W	6200N	07000W	6300N	07500W	6230N	08000W		
MUC	YYZ	5100N	00900W	4700N	05000W	4108N	06700W								
NAN	ANC														
NAN	SYD														
NYC	LON	4108N	06700W	4700N	05000W	5100N	00900W								
NYC	OSL	4108N	06700W	4700N	05000W										
NYC	PAR	4108N	06700W	4800N	00600W										
NYC	PTY	2500N	07500W												
NYC	ROM	4108N	06700W	4600N	00800W										
NYC	SEA														
NYC	SJU														
NYC	SNN	4108N	06700W	4700N	05000W										
NYC	STO	4108N	06700W	4700N	05000W										
NYC	VIE	4108N	06700W	4800N	00600W										
NYC	WAW	4108N	06700W	4700N	05000W	6000N	00500W								
OSA	GDX	3400N	14100E	3700N	14700E										
OSA	SEA	3400N	14100E	5000N	17900W										
OSA	SFO	3400N	14100E												
OSA	SIN	3300N	13700E	0600N	10800E										
OSA	SYD	0500S	15400E	2000S	15500E	2500S	15500E	3230S	15400E						
OSA	YVR	3400N	14100E	5000N	17900W										
PAR	BAH	4530N	01221E	4000N	01900E	3720N	01947E	3425N	02400E	3110N	03325E	2845N	03440E		
PAR	DKR	4200N	01700W	2000N	02000W										
PAR	GDX	6230N	00300E	7200N	02500E	7200N	13230E								
PAR	MIA	4800N	00600W												
PAR	PHL	5100N	00900W	4700N	05000W	4108N	06700W								
PAR	SFO	5100N	00900W	5800N	04500W	6100N	06500W	6200N	07000W	6300N	07500W	6230N	08000W		
PAR	STL	5100N	00900W	4700N	05000W	4108N	06700W								
PAR	TLV	4530N	01221E	4000N	01900E	3720N	01947E	3425N	02400E						
PAR	WAS	4800N	00600W	4108N	06700W										
PAR	YMQ	4800N	00600W	4108N	06700W										
PAR	YYZ	5100N	00900W	4700N	05000W	4108N	06700W								
PEK	SIN	3900N	11800E	3800N	12300E	3000N	12300E	0800N	10800E						
PER	SYD	3500S	11300E	4500S	15000E										
PER	TYO	0100N	11930E	0500N	12600E	3000N	13500E								
POM	HKG	0330S	14700E	2000N	12200E										
POM	SYD	2000S	15500E	2500S	15500E	3230S	15400E								

Origin	Dest.	Waypoint 1 Lat.	Waypoint 1 Long.	Waypoint 2 Lat.	Waypoint 2 Long.	Waypoint 3 Lat.	Waypoint 3 Long.	Waypoint 4 Lat.	Waypoint 4 Long.	Waypoint 5 Lat.	Waypoint 5 Long.	Waypoint 6 Lat.	Waypoint 6 Long.	Waypoint 7 Lat.	Waypoint 7 Long.
PPT	GUM														
PPT	SYD														
RIO	ACA	2000S	07500W	0500S	08300W										
RIO	DKR	2000S	03500W												
ROM	WAS	4106N	06700W												
ROM	YMQ	5100N	00900W	4106N	06700W										
ROM	YYZ	4600N	00800W	4106N	06700W										
SEA	OSA	5000N	17900W	3400N	14100E										
SEA	TYO	5000N	17900W												
SEA	WAS														
SEL	SIN	3500N	12500E	3000N	12500E	0800N	10800E								
SEL	TYO														
SFO	HNL														
SFO	TYO														
SHA	SIN	3000N	12500E	0800N	10800E										
SIN	SYD	0307S	10900E	0700S	12000E	1000S	14200E	2000S	15500E	2500S	15500E	3230S	15400E		
SIN	TPE	0600N	10800E												
SIN	TYO	0600N	10800E	3300N	13700E										
SJU	RIO	1435N	06100W	0730S	03200W	2000S	03500W								
SJU	WAS														
SJU	YYZ	4106N	06700W												
SYD	HNL	2500S	16500E												
SYD	TPE	3230S	15400E	2500S	15500E	2000S	15500E	1000S	15200E	0330S	14700E				
SYD	TYO	3230S	15400E	2500S	15500E	2000S	15500E	0500S	15400E						
TYO	LAX														
TYO	MNL														
TYO	PEK	3400N	14100E	3000N	13000E	3500N	12500E	3800N	12300E	3900N	11800E				
TYO	SEA	5000N	17900W												
TYO	SEL														
TYO	SFO														
TYO	SIN	3300N	13700E	0800N	10800E										
TYO	TPE	3300N	13700E												
TYO	YVR	5000N	17900W												
YVR	YYZ														
YYC	LAX														

Appendix E. Universal Airline System Scheduling

The passenger demand for HSCT service between city-pairs is determined by forecast growth rates and the HSCT market penetration. Once the demands between city-pairs are determined, an acceptable schedule for the HSCT fleet must be created. The schedule is built using a Boeing-developed "Sequential Itinerary" model which dynamically links the cities and demands in the HSCT route network, finding a suitable set of city-pairs for each airplane to serve. The model accounts for airport curfews and for passenger-preferred departure and arrival time "windows". The following is a brief explanation of the model operation:

(Refer to Figure E-1). At the start of the operational day at city "A", the model examines all possible routes that could be flown to carry demand from city "A", looking ahead one leg beyond the first destination. Passenger preference time windows for departure and arrival and airport curfews will likely limit the routes that can be served. In this example, flights are restricted to A-B, then B-F or B-G.

The first airplane is assigned to route A-B (Figure E-2, I). At B, the model looks ahead for the routes to serve which will minimize the time on the ground at B. The model assumes that the minimum ground time for a "turn", that is the end of a flight number, is 1.5 hours. The minimum ground time for a through stop, that is an intermediate stop in the flight required for refueling, is 1.0 hours. In this example (Figure E-2, II), serving B-F then F-P will require stopping at F until the airplane can clear the preference/curfew "window" at P. Since the ground time to serve B-F-P would be longer than that required to serve B-G and then G-K, the model assigns the airplane to the latter routes.

As the airplane "flies" the city-pairs, the model tracks accumulated time for that airplane. The operational day for the airplane (block time for the flights, ground time for "turns" and through stops) is limited to 24 hours less a set maintenance interval, since the model logic works with daily demand. The model uses the 24 hour limit as well as the preference/curfew "windows" in assigning routes. The time limit is obviously more restrictive near the end of the operational day.

As airplane number 1 reaches city P, (Figure E-2, III) its operational day ends with an accumulated time of 20+ hours. At that point airplane number 2 is assigned to serve the cities that receive demand from P. The model schedules airplane 2 in the same manner as number 1, linking together cities which have HSCT demand assigned until the end of the operational day for airplane 2, at which point airplane 3 is assigned. This process continues until all the city-pair demand is served, which takes 500 airplanes and 500 "airplane-days" in the base case. While the model links single airplanes and itineraries sequentially, the results are the same as if multiple airplanes operated together at the same time on the schedule determined by the model.

"Sequential Itinerary" Scheduling Model

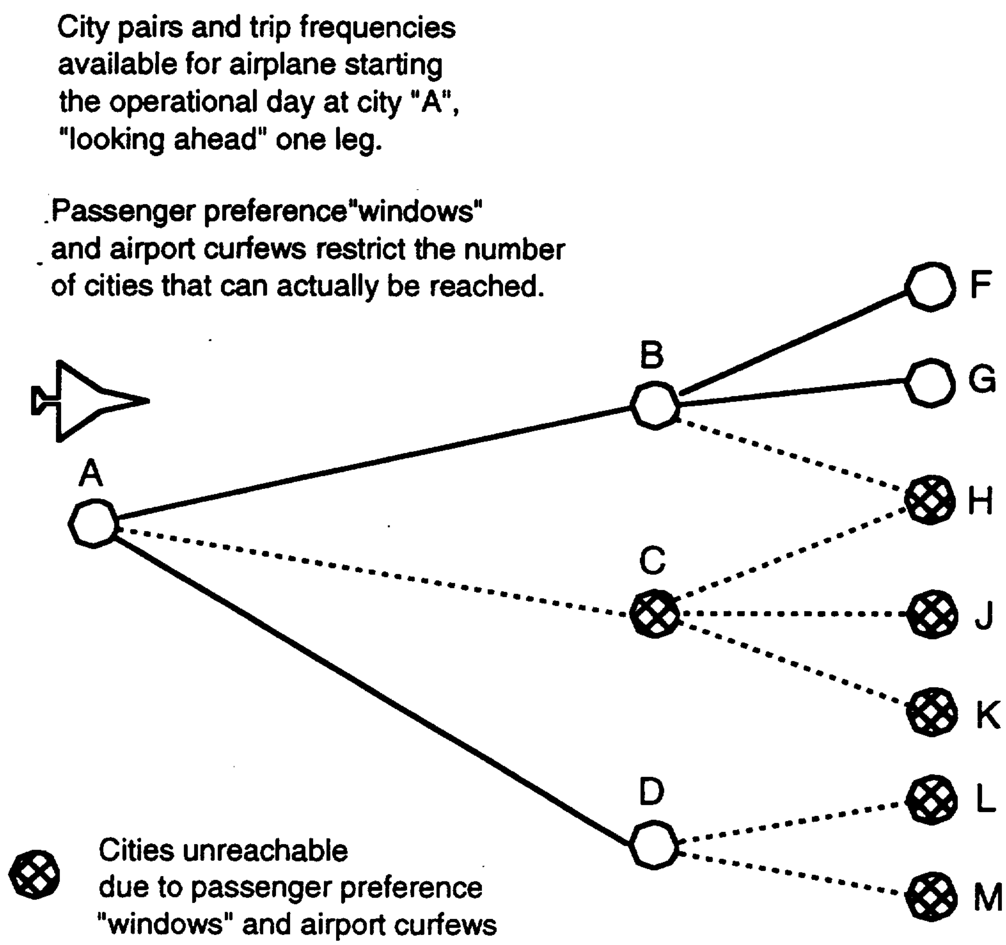

Figure E-1. Sequential Intinerary Scheduling Model
Schematic, 1 airplane

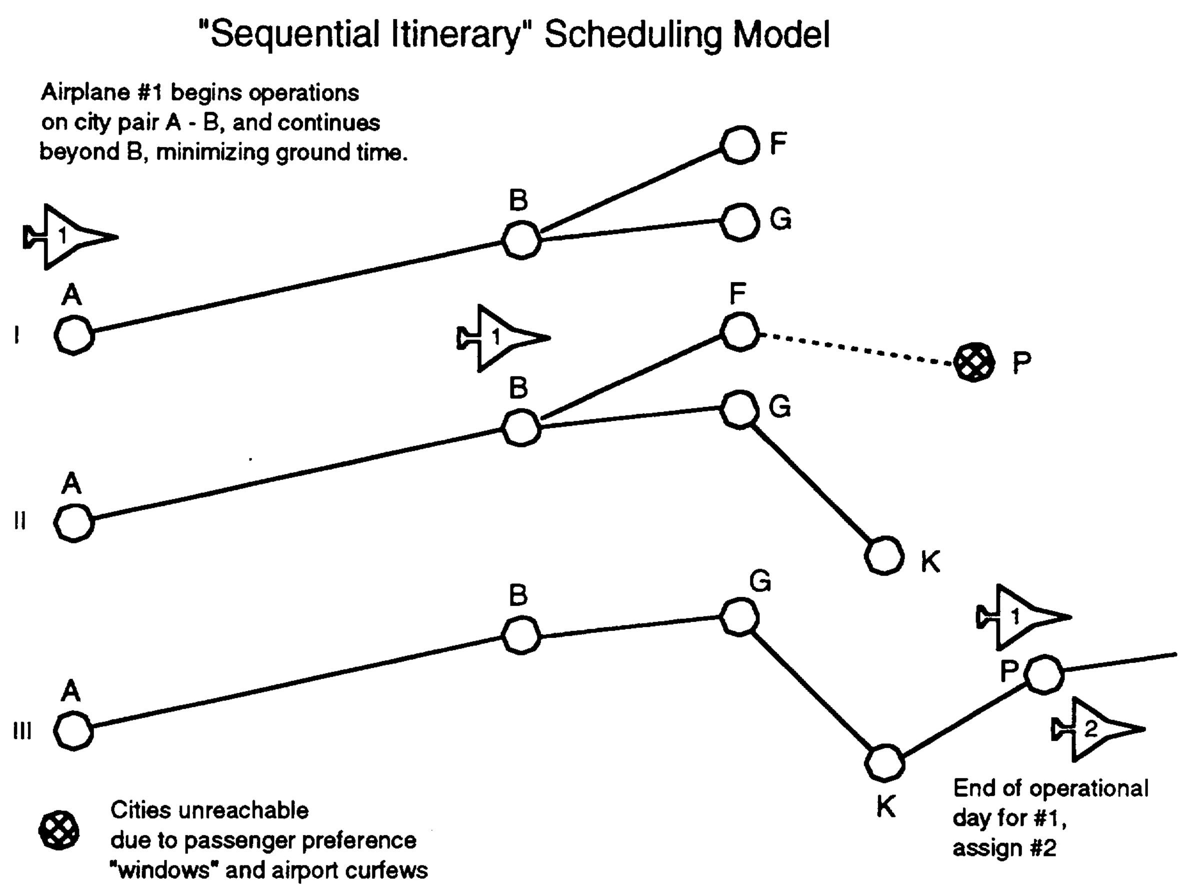

Figure E-2. Sequential Itinerary Scheduling Model Schematic, 3 airplanes.

Table E-1 shows the details of the scheduling of the first 5 airplanes in the 1994 HSCT emissions route system. Because of its speed, the HSCT has the ability to serve a large set of cities and still remain within the preference/curfew time "windows", which are always defined in local time. Thus airplane #1 in the example in Table E-1 begins the day in New York at 0800 New York time, flies to Warsaw and back, then on to Tokyo via Seattle, ending its day at 2023 local time after the short flight from Tokyo to Manila. Airplane #2 starts at Manila at 2153, and can reach Singapore at 2335, then off to Sydney, arriving at 0701 the next morning. From Sydney, the airplane can reach Tokyo at 1131, then to Washington via Seattle, arriving at 0815 local time. Airplane #3 starts from Washington, and ends its day in Guam. Airplane #4 starts in Guam and ends up in Singapore, airplane #5 starts in Singapore and ends up back in Singapore after six trips. Airplane #6 starts in Singapore, and ends its day in Los Angeles. Airplane #7 starts in Los Angeles and ends its day in Seattle and so on until all demand on all city pairs is satisfied.

Table E-1. HSCT "Sequential Itinerary" Scheduling Model

Airplane #	Flight #	Origin	Dest.	Via	Local Time Depart	Local Time Arrive	Block Time (Hrs)	Ground Time (Hrs) (Turn)	Ground Time (Hrs) (at Via Cities)
1	1	NYC	WAW		800	1744	3.8	1.5	
1	2	WAW	NYC		1913	1703	3.8	1.5	
1	3	NYC	TYO	SEA	1832	1826	8.4	1.0	1.0
1	4	TYO	MNL		1925	2023	2.0		
						Totals	17.9	4.0	1.0
					Operational Day Hours		22.8		
2	5	MNL	SIN		2153	2335	1.7	1.5	
2	6	SIN	SYD		105	701	3.9	1.5	
2	7	SYD	TYO		831	1131	4.0	1.5	
2	8	TYO	WAS	SEA	1301	745	8.2		1.0
						Totals	17.8	4.5	1.0
					Operational Day Hours		23.3		
3	9	WAS	TYO	SEA	937	907	8.2	1.2	1.0
3	10	TYO	YVR		1018	2114	4.0	1.5	
3	11	YVR	TYO		2243	1943	4.0	1.5	
3	12	TYO	GUM		2113	2358	1.7		
						Totals	17.8	4.2	1.0
					Operational Day Hours		23.0		
4	13	GUM	TYO		645	728	1.7	1.5	
4	14	TYO	SYD		858	1400	4.0	1.5	
4	15	SYD	TPE		1529	1726	4.0	1.5	
4	16	TPE	SIN		1856	2104	2.1		
						Totals	11.8	4.5	0.0
					Operational Day Hours		16.3		
5	17	SIN	MRU		2234	2150	3.2	1.5	
5	18	MRU	SIN		2320	630	3.2	1.5	
5	19	SIN	TYO		759	1151	2.9	1.5	
5	20	TYO	SIN		1321	1515	2.9	1.5	
5	21	SIN	TPE		1645	1847	2.1	1.5	
5	22	TPE	SIN		2016	2224	2.1		
						Totals	16.4	7.5	0.0
					Operational Day Hours		23.8		

Appendix F. Altitude Distribution of Emissions for Mach 2.4 HSCT fleets

This appendix contains the tables which summarize the different Mach 2.4 HSCT emission scenarios. For each of the scenarios considered, the fuel burned and emissions (NOx, CO, and hydrocarbons) were summed over latitude and longitude and tabulated as a function of altitude in 1 km altitude increments (the resolution of the data set).

Cumulative fractions of fuel burned and emissions were calculated from the ground up to provide a simple way to evaluate how the emissions were distributed vertically. In addition, the effective emission index for each altitude band was calculated and tabulated.

The global total of fuel burned and emissions were calculated and listed at the bottom of each table. Also, included is the effective emission index for NOx, CO, and hydrocarbons, globally averaged over all locations and altitudes.

For the charts shown, the notation 1.00E+08 is equivalent to 1.00×10^8. The emissions are in units of kilograms per year and the emission indices have units of grams of emissions per kilogram of fuel burned.

US Standard Atmosphere (1976) pressures and temperatures were used in the calculations. These altitudes correspond to the geopotential altitudes of the US Standard Atmosphere grid.

Table F-1. Fuel burned, emissions, cumulative fractions of emissions, and emission indices as a function of altitude (Summed over Latitude and Longitude) for the Mach 2.4 (Nominal EI(NOx)=5) HSCT fleet only, assuming 500 HSCTs are flying on the universal network.

Altitude Band (km)	Fuel (kg/year)	cum fuel (%)	NOx (kg/year)	cum NOx (%)	HC (kg/year)	cum HC (%)	CO (kg/year)	cum CO (%)	EI(NOx)	EI(HC)	EI(CO)
0 - 1	2.32E+09	2.82%	1.66E+07	3.11%	2.89E+06	9.75%	2.72E+07	11.26%	7.17	1.25	11.73
1 - 2	8.34E+08	3.83%	6.88E+06	4.39%	4.67E+05	11.32%	2.94E+06	12.48%	8.24	0.56	3.53
2 - 3	8.34E+08	4.85%	6.88E+06	5.68%	4.68E+05	12.90%	2.94E+06	13.70%	8.24	0.56	3.53
3 - 4	8.36E+08	5.87%	6.89E+06	6.97%	4.68E+05	14.48%	2.94E+06	14.92%	8.24	0.56	3.52
4 - 5	8.34E+08	6.88%	6.87E+06	8.25%	4.67E+05	16.05%	2.94E+06	16.14%	8.24	0.56	3.53
5 - 6	8.34E+08	7.90%	6.88E+06	9.54%	4.68E+05	17.63%	2.95E+06	17.36%	8.24	0.56	3.53
6 - 7	8.34E+08	8.92%	6.88E+06	10.82%	4.68E+05	19.20%	2.95E+06	18.58%	8.24	0.56	3.53
7 - 8	8.35E+08	9.93%	6.88E+06	12.11%	4.68E+05	20.78%	2.95E+06	19.80%	8.24	0.56	3.53
8 - 9	1.12E+09	11.29%	9.23E+06	13.84%	5.94E+05	22.79%	4.22E+06	21.55%	8.26	0.53	3.77
9 - 10	2.87E+09	14.79%	2.39E+07	18.30%	1.33E+06	27.26%	1.08E+07	26.02%	8.32	0.46	3.76
10 - 11	3.11E+09	18.58%	2.60E+07	23.17%	1.36E+06	31.86%	9.96E+06	30.15%	8.37	0.44	3.20
11 - 12	2.30E+09	21.38%	1.94E+07	26.81%	9.61E+05	35.10%	5.25E+06	32.32%	8.43	0.42	2.28
12 - 13	3.41E+09	25.53%	2.87E+07	32.18%	1.36E+06	39.69%	9.13E+06	36.11%	8.43	0.40	2.68
13 - 14	1.77E+09	27.68%	1.52E+07	35.03%	5.55E+05	41.56%	1.08E+06	36.55%	8.61	0.31	0.61
14 - 15	1.77E+09	29.84%	1.53E+07	37.88%	5.56E+05	43.43%	1.08E+06	37.00%	8.61	0.31	0.61
15 - 16	1.77E+09	32.00%	1.52E+07	40.73%	5.55E+05	45.30%	1.08E+06	37.45%	8.61	0.31	0.61
16 - 17	1.77E+09	34.15%	1.52E+07	43.58%	5.55E+05	47.18%	1.08E+06	37.90%	8.61	0.31	0.61
17 - 18	3.19E+09	38.04%	2.25E+07	47.80%	9.63E+05	50.42%	5.49E+06	40.17%	7.06	0.30	1.72
18 - 19	1.28E+10	53.61%	7.21E+07	61.28%	3.71E+06	62.94%	3.49E+07	54.65%	5.64	0.29	2.73
19 - 20	2.40E+10	82.78%	1.30E+08	85.66%	6.91E+06	86.25%	6.87E+07	83.11%	5.44	0.29	2.87
20 - 21	1.41E+10	100.00%	7.67E+07	100.00%	4.08E+06	100.00%	4.08E+07	100.00%	5.42	0.29	2.88
Global Total	8.21E+10		5.35E+08		2.97E+07		2.41E+08		6.51	0.36	2.94

Table F-2. Fuel burned, emissions, cumulative fractions of emissions, and emission indices as a function of altitude (Summed over Latitude and Longitude) for the Mach 2.4 (Nominal EI(NOx)=5) HSCT fleet only, assuming 1000 HSCTs are flying on the universal network.

Altitude Band (km)	Fuel (kg/year)	cum fuel (%)	NOx (kg/year)	cum NOx (%)	HC (kg/year)	cum HC (%)	CO (kg/year)	cum CO (%)	EI(NOx)	EI(HC)	EI(CO)
0 - 1	5.03E+09	3.21%	3.59E+07	3.46%	6.45E+06	10.97%	6.09E+07	12.81%	7.13	1.28	12.10
1 - 2	1.74E+09	4.32%	1.43E+07	4.83%	1.01E+06	12.68%	6.53E+06	14.19%	8.21	0.58	3.75
2 - 3	1.74E+09	5.43%	1.43E+07	6.21%	1.01E+06	14.40%	6.53E+06	15.56%	8.21	0.58	3.75
3 - 4	1.74E+09	6.54%	1.43E+07	7.59%	1.01E+06	16.11%	6.53E+06	16.93%	8.21	0.58	3.75
4 - 5	1.74E+09	7.65%	1.43E+07	8.96%	1.01E+06	17.83%	6.56E+06	18.31%	8.21	0.58	3.77
5 - 6	1.74E+09	8.76%	1.43E+07	10.34%	1.01E+06	19.55%	6.56E+06	19.69%	8.21	0.58	3.77
6 - 7	1.74E+09	9.87%	1.43E+07	11.71%	1.01E+06	21.27%	6.56E+06	21.07%	8.21	0.58	3.77
7 - 8	1.74E+09	10.98%	1.43E+07	13.09%	1.01E+06	22.99%	6.56E+06	22.45%	8.21	0.58	3.77
8 - 9	2.15E+09	12.35%	1.77E+07	14.79%	1.19E+06	25.01%	8.39E+06	24.22%	8.23	0.56	3.91
9 - 10	5.17E+09	15.65%	4.29E+07	18.92%	2.48E+06	29.22%	2.02E+07	28.46%	8.30	0.48	3.91
10 - 11	6.47E+09	19.78%	5.40E+07	24.12%	2.94E+06	34.22%	2.29E+07	33.28%	8.34	0.45	3.54
11 - 12	5.83E+09	23.50%	4.89E+07	28.83%	2.55E+06	38.57%	1.74E+07	36.95%	8.38	0.44	2.99
12 - 13	7.69E+09	28.40%	6.46E+07	35.05%	3.15E+06	43.92%	2.25E+07	41.69%	8.41	0.41	2.93
13 - 14	3.55E+09	30.67%	3.05E+07	37.99%	1.12E+06	45.84%	2.29E+06	42.17%	8.61	0.32	0.65
14 - 15	3.55E+09	32.93%	3.06E+07	40.94%	1.13E+06	47.75%	2.29E+06	42.65%	8.61	0.32	0.65
15 - 16	3.55E+09	35.20%	3.05E+07	43.88%	1.12E+06	49.66%	2.29E+06	43.14%	8.61	0.32	0.65
16 - 17	3.55E+09	37.46%	3.05E+07	46.82%	1.12E+06	51.58%	2.29E+06	43.62%	8.61	0.32	0.65
17 - 18	5.45E+09	40.94%	4.03E+07	50.70%	1.67E+06	54.42%	8.21E+06	45.34%	7.39	0.31	1.50
18 - 19	1.98E+10	53.55%	1.14E+08	61.70%	5.77E+06	64.24%	5.21E+07	56.30%	5.78	0.29	2.64
19 - 20	4.15E+10	80.03%	2.28E+08	83.63%	1.20E+07	84.64%	1.18E+08	81.06%	5.49	0.29	2.84
20 - 21	3.13E+10	100.00%	1.70E+08	100.00%	9.03E+06	100.00%	9.01E+07	100.00%	5.43	0.29	2.88
Global Total	1.57E+11		1.04E+09		5.88E+07		4.76E+08		6.62	0.38	3.03

Table F-3. Fuel burned, emissions, cumulative fractions of emissions, and emission indices as a function of altitude (Summed over Latitude and Longitude) for the Mach 2.4 (Nominal EI(NOx)=5) HSCT fleet only, assuming 500 HSCTs are flying on the 1993 AESA assessment network. (revised from NASA CR 4592)

Altitude Band (km)	Fuel (kg/year)	cum fuel (%)	NOx (kg/year)	cum NOx (%)	HC (kg/year)	cum HC (%)	CO (kg/year)	cum CO (%)	EI(NOx)	EI(HC)	EI(CO)
0 - 1	2.32E+09	2.84%	1.66E+07	3.09%	2.95E+06	9.88%	2.78E+07	11.45%	7.17	1.27	11.98
1 - 2	8.47E+08	3.88%	6.97E+06	4.39%	4.77E+05	11.48%	3.02E+06	12.69%	8.24	0.56	3.57
2 - 3	8.47E+08	4.91%	6.97E+06	5.69%	4.77E+05	13.07%	3.02E+06	13.94%	8.24	0.56	3.57
3 - 4	8.47E+08	5.95%	6.97E+06	6.99%	4.77E+05	14.67%	3.02E+06	15.19%	8.24	0.56	3.57
4 - 5	8.47E+08	6.99%	6.97E+06	8.29%	4.77E+05	16.27%	3.02E+06	16.43%	8.24	0.56	3.57
5 - 6	8.47E+08	8.02%	6.97E+06	9.58%	4.77E+05	17.87%	3.02E+06	17.68%	8.24	0.56	3.57
6 - 7	8.47E+08	9.06%	6.97E+06	10.88%	4.77E+05	19.47%	3.02E+06	18.93%	8.24	0.56	3.57
7 - 8	8.47E+08	10.10%	6.97E+06	12.18%	4.77E+05	21.07%	3.02E+06	20.18%	8.24	0.56	3.57
8 - 9	1.21E+09	11.59%	1.00E+07	14.05%	6.33E+05	23.18%	4.45E+06	22.01%	8.27	0.52	3.66
9 - 10	2.57E+09	14.74%	2.15E+07	18.05%	1.16E+06	27.07%	8.44E+06	25.49%	8.35	0.45	3.28
10 - 11	3.25E+09	18.72%	2.72E+07	23.11%	1.42E+06	31.83%	1.04E+07	29.79%	8.37	0.44	3.21
11 - 12	3.25E+09	22.71%	2.73E+07	28.20%	1.39E+06	36.49%	9.55E+06	33.73%	8.39	0.43	2.94
12 - 13	4.38E+09	28.07%	3.68E+07	35.04%	1.79E+06	42.48%	1.33E+07	39.22%	8.40	0.41	3.04
13 - 14	1.75E+09	30.22%	1.51E+07	37.85%	5.50E+05	44.32%	1.07E+06	39.66%	8.61	0.31	0.61
14 - 15	1.75E+09	32.37%	1.51E+07	40.66%	5.50E+05	46.16%	1.07E+06	40.10%	8.61	0.31	0.61
15 - 16	1.75E+09	34.51%	1.51E+07	43.47%	5.50E+05	48.00%	1.07E+06	40.54%	8.61	0.31	0.61
16 - 17	1.75E+09	36.66%	1.51E+07	46.28%	5.50E+05	49.84%	1.07E+06	40.98%	8.61	0.31	0.61
17 - 18	3.36E+09	40.78%	2.33E+07	50.63%	1.01E+06	53.23%	6.06E+06	43.47%	6.94	0.30	1.80
18 - 19	1.26E+10	56.23%	7.10E+07	63.84%	3.66E+06	65.49%	3.45E+07	57.71%	5.63	0.29	2.74
19 - 20	2.27E+10	84.03%	1.24E+08	86.84%	6.55E+06	87.41%	6.50E+07	84.51%	5.45	0.29	2.86
20 - 21	1.30E+10	100.00%	7.07E+07	100.00%	3.76E+06	100.00%	3.76E+07	100.00%	5.42	0.29	2.88
Global Total	8.16E+10		5.37E+08		2.99E+07		2.42E+08		6.58	0.37	2.97

Table F-4. Fuel burned, emissions, cumulative fractions of emissions, and emission indices as a function of altitude (Summed over Latitude and Longitude) for the Mach 2.4 (Nominal EI(NOx)=15) HSCT fleet only, assuming 500 HSCTs are flying on the universal network.

Altitude Band (km)	Fuel (kg/year)	cum fuel (%)	NOx (kg/year)	cum NOx (%)	HC (kg/year)	cum HC (%)	CO (kg/year)	cum CO (%)	EI(NOx)	EI(HC)	EI(CO)
0 - 1	2.32E+09	2.82%	3.54E+07	2.39%	2.89E+06	9.75%	2.72E+07	11.26%	15.28	1.25	11.73
1 - 2	8.34E+08	3.83%	1.92E+07	3.69%	4.67E+05	11.32%	2.94E+06	12.48%	22.97	0.56	3.53
2 - 3	8.34E+08	4.85%	1.92E+07	4.99%	4.68E+05	12.90%	2.94E+06	13.70%	22.97	0.56	3.53
3 - 4	8.36E+08	5.87%	1.92E+07	6.28%	4.68E+05	14.48%	2.94E+06	14.92%	22.98	0.56	3.52
4 - 5	8.34E+08	6.88%	1.92E+07	7.58%	4.67E+05	16.05%	2.94E+06	16.14%	22.97	0.56	3.53
5 - 6	8.34E+08	7.90%	1.92E+07	8.88%	4.68E+05	17.63%	2.95E+06	17.36%	22.97	0.56	3.53
6 - 7	8.34E+08	8.92%	1.92E+07	10.17%	4.68E+05	19.20%	2.95E+06	18.58%	22.96	0.56	3.53
7 - 8	8.35E+08	9.93%	1.92E+07	11.47%	4.68E+05	20.78%	2.95E+06	19.80%	22.97	0.56	3.53
8 - 9	1.12E+09	11.29%	2.15E+07	12.93%	5.94E+05	22.79%	4.22E+06	21.55%	19.24	0.53	3.77
9 - 10	2.87E+09	14.79%	4.15E+07	15.73%	1.33E+06	27.26%	1.08E+07	26.02%	14.45	0.46	3.76
10 - 11	3.11E+09	18.58%	5.16E+07	19.22%	1.36E+06	31.86%	9.96E+06	30.15%	16.57	0.44	3.20
11 - 12	2.30E+09	21.38%	4.94E+07	22.56%	9.61E+05	35.10%	5.25E+06	32.32%	21.44	0.42	2.28
12 - 13	3.41E+09	25.53%	5.94E+07	26.58%	1.36E+06	39.69%	9.13E+06	36.11%	17.44	0.40	2.68
13 - 14	1.77E+09	27.68%	4.54E+07	29.65%	5.55E+05	41.56%	1.08E+06	36.55%	25.65	0.31	0.61
14 - 15	1.77E+09	29.84%	4.54E+07	32.72%	5.56E+05	43.43%	1.08E+06	37.00%	25.65	0.31	0.61
15 - 16	1.77E+09	32.00%	4.54E+07	35.79%	5.55E+05	45.30%	1.08E+06	37.45%	25.65	0.31	0.61
16 - 17	1.77E+09	34.15%	4.54E+07	38.86%	5.55E+05	47.18%	1.08E+06	37.90%	25.65	0.31	0.61
17 - 18	3.19E+09	38.04%	6.73E+07	43.41%	9.63E+05	50.42%	5.49E+06	40.17%	21.06	0.30	1.72
18 - 19	1.28E+10	53.61%	2.16E+08	58.02%	3.71E+06	62.94%	3.49E+07	54.65%	16.88	0.29	2.73
19 - 20	2.40E+10	82.78%	3.91E+08	84.45%	6.91E+06	86.25%	6.87E+07	83.11%	16.31	0.29	2.87
20 - 21	1.41E+10	100.00%	2.30E+08	100.00%	4.08E+06	100.00%	4.08E+07	100.00%	16.25	0.29	2.88
Global Total	8.21E+10		1.48E+09		2.97E+07		2.41E+08		18.00	0.36	2.94

Table F-5. Fuel burned, emissions, cumulative fractions of emissions, and emission indices as a function of altitude (Summed over Latitude and Longitude) for the Mach 2.4 (Nominal EI(NOx)=15) HSCT fleet only, assuming 1000 HSCTs are flying on the universal network.

Altitude Band (km)	Fuel (kg/year)	cum fuel (%)	NOx (kg/year)	cum NOx (%)	HC (kg/year)	cum HC (%)	CO (kg/year)	cum CO (%)	EI(NOx)	EI(HC)	EI(CO)
0 - 1	5.03E+09	3.21%	7.55E+07	2.68%	6.45E+06	10.97%	6.09E+07	12.81%	14.99	1.28	12.10
1 - 2	1.74E+09	4.32%	3.96E+07	4.08%	1.01E+06	12.68%	6.53E+06	14.19%	22.77	0.58	3.75
2 - 3	1.74E+09	5.43%	3.96E+07	5.48%	1.01E+06	14.40%	6.53E+06	15.56%	22.77	0.58	3.75
3 - 4	1.74E+09	6.54%	3.96E+07	6.89%	1.01E+06	16.11%	6.53E+06	16.93%	22.77	0.58	3.75
4 - 5	1.74E+09	7.65%	3.96E+07	8.29%	1.01E+06	17.83%	6.56E+06	18.31%	22.75	0.58	3.77
5 - 6	1.74E+09	8.76%	3.96E+07	9.70%	1.01E+06	19.55%	6.56E+06	19.69%	22.75	0.58	3.77
6 - 7	1.74E+09	9.87%	3.96E+07	11.10%	1.01E+06	21.27%	6.56E+06	21.07%	22.74	0.58	3.77
7 - 8	1.74E+09	10.98%	3.96E+07	12.51%	1.01E+06	22.99%	6.56E+06	22.45%	22.75	0.58	3.77
8 - 9	2.15E+09	12.35%	4.30E+07	14.03%	1.19E+06	25.01%	8.39E+06	24.22%	20.00	0.56	3.91
9 - 10	5.17E+09	15.65%	7.54E+07	16.70%	2.48E+06	29.22%	2.02E+07	28.46%	14.59	0.48	3.91
10 - 11	6.47E+09	19.78%	9.95E+07	20.23%	2.94E+06	34.22%	2.29E+07	33.28%	15.36	0.45	3.54
11 - 12	5.83E+09	23.50%	1.05E+08	23.96%	2.55E+06	38.57%	1.74E+07	36.95%	18.03	0.44	2.99
12 - 13	7.69E+09	28.40%	1.26E+08	28.44%	3.15E+06	43.92%	2.25E+07	41.69%	16.42	0.41	2.93
13 - 14	3.55E+09	30.67%	9.09E+07	31.66%	1.12E+06	45.84%	2.29E+06	42.17%	25.62	0.32	0.65
14 - 15	3.55E+09	32.93%	9.10E+07	34.89%	1.13E+06	47.75%	2.29E+06	42.65%	25.62	0.32	0.65
15 - 16	3.55E+09	35.20%	9.09E+07	38.11%	1.12E+06	49.66%	2.29E+06	43.14%	25.62	0.32	0.65
16 - 17	3.55E+09	37.46%	9.09E+07	41.34%	1.12E+06	51.58%	2.29E+06	43.62%	25.62	0.32	0.65
17 - 18	5.45E+09	40.94%	1.20E+08	45.60%	1.67E+06	54.42%	8.21E+06	45.34%	22.03	0.31	1.50
18 - 19	1.98E+10	53.55%	3.42E+08	57.73%	5.77E+06	64.24%	5.21E+07	56.30%	17.30	0.29	2.64
19 - 20	4.15E+10	80.03%	6.82E+08	81.93%	1.20E+07	84.64%	1.18E+08	81.06%	16.45	0.29	2.84
20 - 21	3.13E+10	100.00%	5.09E+08	100.00%	9.03E+06	100.00%	9.01E+07	100.00%	16.27	0.29	2.88
Global Total	1.57E+11		2.82E+09		5.88E+07		4.76E+08		17.99	0.38	3.03

Table F-6. Fuel burned, emissions, cumulative fractions of emissions, and emission indices as a function of altitude (Summed over Latitude and Longitude) for the Mach 2.4 (Nominal EI(NOx)=15) HSCT fleet only, assuming 500 HSCTs are flying on the 1993 AESA assessment network. (revised from NASA CR 4592)

Altitude Band (km)	Fuel (kg/year)	cum fuel (%)	NOx (kg/year)	cum NOx (%)	HC (kg/year)	cum HC (%)	CO (kg/year)	cum CO (%)	EI(NOx)	EI(HC)	EI(CO)
0 - 1	2.32E+09	2.84%	3.53E+07	2.41%	2.95E+06	9.88%	2.78E+07	11.45%	15.22	1.27	11.98
1 - 2	8.47E+08	3.88%	1.94E+07	3.74%	4.77E+05	11.48%	3.02E+06	12.69%	22.93	0.56	3.57
2 - 3	8.47E+08	4.91%	1.94E+07	5.07%	4.77E+05	13.07%	3.02E+06	13.94%	22.93	0.56	3.57
3 - 4	8.47E+08	5.95%	1.94E+07	6.40%	4.77E+05	14.67%	3.02E+06	15.19%	22.93	0.56	3.57
4 - 5	8.47E+08	6.99%	1.94E+07	7.72%	4.77E+05	16.27%	3.02E+06	16.43%	22.93	0.56	3.57
5 - 6	8.47E+08	8.02%	1.94E+07	9.05%	4.77E+05	17.87%	3.02E+06	17.68%	22.93	0.56	3.57
6 - 7	8.47E+08	9.06%	1.94E+07	10.38%	4.77E+05	19.47%	3.02E+06	18.93%	22.93	0.56	3.57
7 - 8	8.47E+08	10.10%	1.94E+07	11.71%	4.77E+05	21.07%	3.02E+06	20.18%	22.93	0.56	3.57
8 - 9	1.21E+09	11.59%	2.34E+07	13.31%	6.33E+05	23.18%	4.45E+06	22.01%	19.28	0.52	3.66
9 - 10	2.57E+09	14.74%	4.35E+07	16.28%	1.16E+06	27.07%	8.44E+06	25.49%	16.92	0.45	3.28
10 - 11	3.25E+09	18.72%	5.37E+07	19.96%	1.42E+06	31.83%	1.04E+07	29.79%	16.50	0.44	3.21
11 - 12	3.25E+09	22.71%	5.74E+07	23.88%	1.39E+06	36.49%	9.55E+06	33.73%	17.65	0.43	2.94
12 - 13	4.38E+09	28.07%	6.83E+07	28.55%	1.79E+06	42.48%	1.33E+07	39.22%	15.61	0.41	3.04
13 - 14	1.75E+09	30.22%	4.50E+07	31.63%	5.50E+05	44.32%	1.07E+06	39.66%	25.65	0.31	0.61
14 - 15	1.75E+09	32.37%	4.50E+07	34.71%	5.50E+05	46.16%	1.07E+06	40.10%	25.65	0.31	0.61
15 - 16	1.75E+09	34.51%	4.50E+07	37.78%	5.50E+05	48.00%	1.07E+06	40.54%	25.65	0.31	0.61
16 - 17	1.75E+09	36.66%	4.50E+07	40.86%	5.50E+05	49.84%	1.07E+06	40.98%	25.65	0.31	0.61
17 - 18	3.36E+09	40.78%	6.97E+07	45.63%	1.01E+06	53.23%	6.06E+06	43.47%	20.73	0.30	1.80
18 - 19	1.26E+10	56.23%	2.13E+08	60.17%	3.66E+06	65.49%	3.45E+07	57.71%	16.86	0.29	2.74
19 - 20	2.27E+10	84.03%	3.70E+08	85.50%	6.55E+06	87.41%	6.50E+07	84.51%	16.33	0.29	2.86
20 - 21	1.30E+10	100.00%	2.12E+08	100.00%	3.76E+06	100.00%	3.76E+07	100.00%	16.26	0.29	2.88
Global Total	8.16E+10		1.46E+09		2.99E+07		2.42E+08		17.91	0.37	2.97

Appendix G. Altitude Distribution of Emissions for Mach 2.0 HSCT fleets

This appendix contains the tables which summarize the different Mach 2.0 HSCT emission scenarios. For each of the scenarios considered, the fuel burned and emissions (NOx, CO, and hydrocarbons) were summed over latitude and longitude and tabulated as a function of altitude in 1 km altitude increments (the resolution of the data set).

Cumulative fractions of fuel burned and emissions were calculated from the ground up to provide a simple way to evaluate how the emissions were distributed vertically. In addition, the effective emission index for each altitude band was calculated and tabulated.

The global total of fuel burned and emissions were calculated and listed at the bottom of each table. Also, included is the effective emission index for NOx, CO, and hydrocarbons, globally averaged over all locations and altitudes.

For the charts shown, the notation 1.00E+08 is equivalent to 1.00×10^8. The emissions are in units of kilograms per year and the emission indices have units of grams of emissions per kilogram of fuel burned.

US Standard Atmosphere (1976) pressures and temperatures were used in the calculations. These altitudes correspond to the geopotential altitudes of the US Standard Atmosphere grid.

Table G-1. Fuel burned, emissions, cumulative fractions of emissions, and emission indices as a function of altitude (Summed over Latitude and Longitude) for the Mach 2.0 (Nominal EI(NOx)=5) HSCT fleet only, assuming passenger demand corresponding to 500 Mach 2.4 HSCTs flying on the universal network.

Altitude Band (km)	Fuel (kg/year)	cum fuel (%)	NOx (kg/year)	cum NOx (%)	HC (kg/year)	cum HC (%)	CO (kg/year)	cum CO (%)	EI(NOx)	EI(HC)	EI(CO)
0 - 1	2.11E+09	2.50%	1.54E+07	3.06%	2.50E+06	8.62%	2.34E+07	9.48%	7.29	1.18	11.08
1 - 2	7.66E+08	3.41%	6.04E+06	4.25%	4.22E+05	10.07%	2.64E+06	10.55%	7.88	0.55	3.45
2 - 3	7.66E+08	4.31%	6.03E+06	5.45%	4.22E+05	11.53%	2.64E+06	11.62%	7.88	0.55	3.45
3 - 4	7.67E+08	5.22%	6.04E+06	6.65%	4.22E+05	12.98%	2.64E+06	12.69%	7.88	0.55	3.45
4 - 5	7.66E+08	6.13%	6.03E+06	7.85%	4.22E+05	14.44%	2.64E+06	13.76%	7.88	0.55	3.45
5 - 6	7.65E+08	7.03%	6.03E+06	9.04%	4.22E+05	15.89%	2.64E+06	14.83%	7.88	0.55	3.45
6 - 7	7.67E+08	7.94%	6.04E+06	10.24%	4.22E+05	17.35%	2.64E+06	15.90%	7.88	0.55	3.45
7 - 8	7.67E+08	8.85%	6.04E+06	11.44%	4.22E+05	18.80%	2.64E+06	16.97%	7.87	0.55	3.45
8 - 9	1.21E+09	10.29%	9.00E+06	13.23%	5.75E+05	20.79%	4.15E+06	18.65%	7.41	0.47	3.41
9 - 10	2.78E+09	13.58%	1.97E+07	17.14%	1.10E+06	24.57%	8.66E+06	22.16%	7.09	0.40	3.12
10 - 11	2.64E+09	16.69%	1.93E+07	20.97%	1.03E+06	28.11%	7.02E+06	25.00%	7.33	0.39	2.66
11 - 12	2.02E+09	19.09%	1.56E+07	24.06%	8.07E+05	30.90%	4.34E+06	26.76%	7.70	0.40	2.14
12 - 13	2.97E+09	22.60%	2.18E+07	28.39%	1.04E+06	34.47%	6.56E+06	29.42%	7.35	0.35	2.21
13 - 14	1.51E+09	24.39%	1.22E+07	30.81%	4.75E+05	36.11%	9.40E+05	29.80%	8.07	0.31	0.62
14 - 15	1.51E+09	26.18%	1.22E+07	33.23%	4.75E+05	37.75%	9.35E+05	30.18%	8.08	0.31	0.62
15 - 16	1.52E+09	27.97%	1.22E+07	35.66%	4.77E+05	39.39%	9.54E+05	30.56%	8.07	0.31	0.63
16 - 17	6.67E+09	35.86%	3.82E+07	43.25%	1.95E+06	46.12%	1.66E+07	37.30%	5.73	0.29	2.50
17 - 18	1.82E+10	57.44%	9.70E+07	62.51%	5.27E+06	64.29%	5.15E+07	58.14%	5.32	0.29	2.82
18 - 19	2.66E+10	88.88%	1.40E+08	90.22%	7.65E+06	90.67%	7.63E+07	89.04%	5.26	0.29	2.87
19 - 20	9.39E+09	100.00%	4.93E+07	100.00%	2.71E+06	100.00%	2.71E+07	100.00%	5.25	0.29	2.88
Global Total	8.45E+10		5.04E+08		2.90E+07		2.47E+08		5.96	0.34	2.92

Table G-2. Fuel burned, emissions, cumulative fractions of emissions, and emission indices as a function of altitude (Summed over Latitude and Longitude) for the Mach 2.0 (Nominal EI(NOx)=5) HSCT fleet only, assuming passenger demand corresponding to 1000 Mach 2.4 HSCTs flying on the universal network.

Altitude Band (km)	Fuel (kg/year)	cum fuel (%)	NOx (kg/year)	cum NOx (%)	HC (kg/year)	cum HC (%)	CO (kg/year)	cum CO (%)	EI(NOx)	EI(HC)	EI(CO)
0 - 1	4.58E+09	2.87%	3.33E+07	3.46%	5.57E+06	9.85%	5.25E+07	10.99%	7.28	1.22	11.46
1 - 2	1.59E+09	3.86%	1.25E+07	4.75%	9.06E+05	11.45%	5.85E+06	12.22%	7.86	0.57	3.68
2 - 3	1.59E+09	4.86%	1.25E+07	6.04%	9.06E+05	13.05%	5.85E+06	13.44%	7.86	0.57	3.68
3 - 4	1.59E+09	5.85%	1.25E+07	7.34%	9.06E+05	14.66%	5.85E+06	14.67%	7.86	0.57	3.68
4 - 5	1.59E+09	6.85%	1.25E+07	8.63%	9.09E+05	16.26%	5.88E+06	15.90%	7.86	0.57	3.70
5 - 6	1.59E+09	7.84%	1.25E+07	9.93%	9.09E+05	17.87%	5.89E+06	17.13%	7.86	0.57	3.70
6 - 7	1.59E+09	8.84%	1.25E+07	11.22%	9.10E+05	19.48%	5.89E+06	18.36%	7.86	0.57	3.70
7 - 8	1.59E+09	9.84%	1.25E+07	12.52%	9.10E+05	21.09%	5.89E+06	19.59%	7.86	0.57	3.70
8 - 9	2.22E+09	11.23%	1.67E+07	14.25%	1.12E+06	23.08%	8.00E+06	21.27%	7.50	0.51	3.60
9 - 10	5.03E+09	14.37%	3.57E+07	17.94%	2.07E+06	26.74%	1.65E+07	24.72%	7.09	0.41	3.28
10 - 11	5.57E+09	17.86%	4.01E+07	22.10%	2.22E+06	30.66%	1.64E+07	28.16%	7.21	0.40	2.95
11 - 12	5.23E+09	21.14%	3.87E+07	26.11%	2.08E+06	34.33%	1.38E+07	31.04%	7.39	0.40	2.63
12 - 13	6.72E+09	25.34%	4.88E+07	31.17%	2.38E+06	38.54%	1.62E+07	34.43%	7.26	0.35	2.41
13 - 14	3.03E+09	27.24%	2.45E+07	33.70%	9.63E+05	40.24%	2.00E+06	34.84%	8.07	0.32	0.66
14 - 15	3.03E+09	29.14%	2.45E+07	36.24%	9.62E+05	41.95%	1.99E+06	35.26%	8.07	0.32	0.66
15 - 16	3.04E+09	31.04%	2.45E+07	38.78%	9.65E+05	43.65%	2.02E+06	35.68%	8.07	0.32	0.66
16 - 17	1.01E+10	37.35%	6.00E+07	45.00%	2.98E+06	48.92%	2.34E+07	40.58%	5.96	0.30	2.33
17 - 18	2.89E+10	55.44%	1.56E+08	61.14%	8.37E+06	63.72%	8.01E+07	57.34%	5.39	0.29	2.77
18 - 19	4.88E+10	85.97%	2.57E+08	87.81%	1.41E+07	88.59%	1.39E+08	86.49%	5.28	0.29	2.86
19 - 20	2.24E+10	100.00%	1.18E+08	100.00%	6.46E+06	100.00%	6.45E+07	100.00%	5.25	0.29	2.88
Global Total	1.60E+11		9.65E+08		5.66E+07		4.78E+08		6.04	0.35	2.99

Table G-3. Fuel burned, emissions, cumulative fractions of emissions, and emission indices as a function of altitude (Summed over Latitude and Longitude) for the Mach 2.0 (Nominal EI(NOx)=5) HSCT fleet only, assuming passenger demand corresponding to 500 Mach 2.4 HSCTs flying on the 1993 AESA assessment network. (revised from NASA CR 4592)

Altitude Band (km)	Fuel (kg/year)	cum fuel (%)	NOx (kg/year)	cum NOx (%)	HC (kg/year)	cum HC (%)	CO (kg/year)	cum CO (%)	EI(NOx)	EI(HC)	EI(CO)
0 - 1	2.11E+09	2.52%	1.54E+07	3.07%	2.55E+06	8.81%	2.39E+07	9.75%	7.32	1.21	11.35
1 - 2	7.76E+08	3.45%	6.11E+06	4.29%	4.30E+05	10.30%	2.71E+06	10.85%	7.87	0.55	3.50
2 - 3	7.76E+08	4.38%	6.11E+06	5.51%	4.30E+05	11.79%	2.71E+06	11.96%	7.87	0.55	3.50
3 - 4	7.76E+08	5.30%	6.11E+06	6.72%	4.30E+05	13.27%	2.71E+06	13.06%	7.87	0.55	3.50
4 - 5	7.76E+08	6.23%	6.11E+06	7.94%	4.30E+05	14.76%	2.71E+06	14.17%	7.87	0.55	3.50
5 - 6	7.76E+08	7.16%	6.11E+06	9.16%	4.30E+05	16.25%	2.71E+06	15.27%	7.87	0.55	3.50
6 - 7	7.76E+08	8.09%	6.11E+06	10.38%	4.30E+05	17.74%	2.71E+06	16.38%	7.87	0.55	3.50
7 - 8	7.76E+08	9.02%	6.11E+06	11.59%	4.30E+05	19.22%	2.71E+06	17.48%	7.87	0.55	3.50
8 - 9	1.15E+09	10.39%	8.58E+06	13.30%	5.56E+05	21.15%	3.90E+06	19.07%	7.49	0.49	3.40
9 - 10	2.48E+09	13.35%	1.80E+07	16.90%	9.88E+05	24.56%	7.04E+06	21.94%	7.28	0.40	2.84
10 - 11	2.80E+09	16.70%	2.04E+07	20.97%	1.09E+06	28.32%	7.56E+06	25.03%	7.30	0.39	2.70
11 - 12	2.90E+09	20.17%	2.13E+07	25.22%	1.11E+06	32.17%	7.35E+06	28.02%	7.37	0.38	2.54
12 - 13	3.82E+09	24.74%	2.74E+07	30.69%	1.33E+06	36.78%	9.46E+06	31.88%	7.18	0.35	2.47
13 - 14	1.51E+09	26.55%	1.22E+07	33.13%	4.76E+05	38.42%	9.38E+05	32.26%	8.08	0.31	0.62
14 - 15	1.51E+09	28.37%	1.22E+07	35.57%	4.76E+05	40.07%	9.38E+05	32.65%	8.08	0.31	0.62
15 - 16	1.52E+09	30.18%	1.23E+07	38.02%	4.78E+05	41.72%	9.54E+05	33.03%	8.07	0.31	0.63
16 - 17	7.01E+09	38.57%	3.99E+07	45.97%	2.05E+06	48.81%	1.77E+07	40.25%	5.70	0.29	2.53
17 - 18	1.75E+10	59.46%	9.30E+07	64.51%	5.04E+06	66.25%	4.92E+07	60.32%	5.33	0.29	2.82
18 - 19	2.53E+10	89.76%	1.33E+08	91.05%	7.30E+06	91.48%	7.27E+07	89.96%	5.26	0.29	2.87
19 - 20	8.56E+09	100.00%	4.49E+07	100.00%	2.47E+06	100.00%	2.46E+07	100.00%	5.25	0.29	2.88
Global Total	8.36E+10		5.02E+08		2.89E+07		2.45E+08		6.00	0.35	2.94

Table G-4. Fuel burned, emissions, cumulative fractions of emissions, and emission indices as a function of altitude (Summed over Latitude and Longitude) for the Mach 2.0 (Nominal EI(NOx)=15) HSCT fleet only, assuming passenger demand corresponding to 500 Mach 2.4 HSCTs flying on the universal network.

Altitude Band (km)	Fuel (kg/year)	cum fuel (%)	NOx (kg/year)	cum NOx (%)	HC (kg/year)	cum HC (%)	CO (kg/year)	cum CO (%)	EI(NOx)	EI(HC)	EI(CO)
0 - 1	2.11E+09	2.50%	3.15E+07	2.13%	2.50E+06	8.62%	2.34E+07	9.48%	14.89	1.18	11.08
1 - 2	7.66E+08	3.41%	1.65E+07	3.25%	4.22E+05	10.07%	2.64E+06	10.55%	21.58	0.55	3.45
2 - 3	7.66E+08	4.31%	1.65E+07	4.37%	4.22E+05	11.53%	2.64E+06	11.62%	21.58	0.55	3.45
3 - 4	7.67E+08	5.22%	1.65E+07	5.49%	4.22E+05	12.98%	2.64E+06	12.69%	21.58	0.55	3.45
4 - 5	7.66E+08	6.13%	1.65E+07	6.61%	4.22E+05	14.44%	2.64E+06	13.76%	21.58	0.55	3.45
5 - 6	7.65E+08	7.03%	1.65E+07	7.73%	4.22E+05	15.89%	2.64E+06	14.83%	21.58	0.55	3.45
6 - 7	7.67E+08	7.94%	1.65E+07	8.85%	4.22E+05	17.35%	2.64E+06	15.90%	21.58	0.55	3.45
7 - 8	7.67E+08	8.85%	1.65E+07	9.97%	4.22E+05	18.80%	2.64E+06	16.97%	21.57	0.55	3.45
8 - 9	1.21E+09	10.29%	2.54E+07	11.69%	5.75E+05	20.79%	4.15E+06	18.65%	20.93	0.47	3.41
9 - 10	2.78E+09	13.58%	5.75E+07	15.59%	1.10E+06	24.57%	8.66E+06	22.16%	20.70	0.40	3.12
10 - 11	2.64E+09	16.69%	5.64E+07	19.40%	1.03E+06	28.11%	7.02E+06	25.00%	21.39	0.39	2.66
11 - 12	2.02E+09	19.09%	4.51E+07	22.46%	8.07E+05	30.90%	4.34E+06	26.76%	22.31	0.40	2.14
12 - 13	2.97E+09	22.60%	6.45E+07	26.83%	1.04E+06	34.47%	6.56E+06	29.42%	21.75	0.35	2.21
13 - 14	1.51E+09	24.39%	3.63E+07	29.29%	4.75E+05	36.11%	9.40E+05	29.80%	24.01	0.31	0.62
14 - 15	1.51E+09	26.18%	3.63E+07	31.75%	4.75E+05	37.75%	9.35E+05	30.18%	24.02	0.31	0.62
15 - 16	1.52E+09	27.97%	3.64E+07	34.21%	4.77E+05	39.39%	9.54E+05	30.56%	23.98	0.31	0.63
16 - 17	6.67E+09	35.86%	1.14E+08	41.95%	1.95E+06	46.12%	1.66E+07	37.30%	17.15	0.29	2.50
17 - 18	1.82E+10	57.44%	2.91E+08	61.65%	5.27E+06	64.29%	5.15E+07	58.14%	15.95	0.29	2.82
18 - 19	2.66E+10	88.88%	4.19E+08	89.99%	7.65E+06	90.67%	7.63E+07	89.04%	15.76	0.29	2.87
19 - 20	9.39E+09	100.00%	1.48E+08	100.00%	2.71E+06	100.00%	2.71E+07	100.00%	15.73	0.29	2.88
Global Total	8.45E+10		1.48E+09		2.90E+07		2.47E+08		17.48	0.34	2.92

Table G-5. Fuel burned, emissions, cumulative fractions of emissions, and emission indices as a function of altitude (Summed over Latitude and Longitude) for the Mach 2.0 (Nominal EI(NOx)=15) HSCT fleet only, assuming passenger demand corresponding to 1000 Mach 2.4 HSCTs flying on the universal network.

Altitude Band (km)	Fuel (kg/year)	cum fuel (%)	NOx (kg/year)	cum NOx (%)	HC (kg/year)	cum HC (%)	CO (kg/year)	cum CO (%)	EI(NOx)	EI(HC)	EI(CO)
0 - 1	4.58E+09	2.87%	6.69E+07	2.37%	5.57E+06	9.85%	5.25E+07	10.99%	14.60	1.22	11.46
1 - 2	1.59E+09	3.86%	3.40E+07	3.58%	9.06E+05	11.45%	5.85E+06	12.22%	21.38	0.57	3.68
2 - 3	1.59E+09	4.86%	3.40E+07	4.79%	9.06E+05	13.05%	5.85E+06	13.44%	21.38	0.57	3.68
3 - 4	1.59E+09	5.85%	3.40E+07	5.99%	9.06E+05	14.66%	5.85E+06	14.67%	21.38	0.57	3.68
4 - 5	1.59E+09	6.85%	3.40E+07	7.20%	9.09E+05	16.26%	5.88E+06	15.90%	21.36	0.57	3.70
5 - 6	1.59E+09	7.84%	3.40E+07	8.40%	9.09E+05	17.87%	5.89E+06	17.13%	21.36	0.57	3.70
6 - 7	1.59E+09	8.84%	3.40E+07	9.61%	9.10E+05	19.48%	5.89E+06	18.36%	21.36	0.57	3.70
7 - 8	1.59E+09	9.84%	3.40E+07	10.82%	9.10E+05	21.09%	5.89E+06	19.59%	21.36	0.57	3.70
8 - 9	2.22E+09	11.23%	4.64E+07	12.47%	1.12E+06	23.08%	8.00E+06	21.27%	20.92	0.51	3.60
9 - 10	5.03E+09	14.37%	1.04E+08	16.14%	2.07E+06	26.74%	1.65E+07	24.72%	20.58	0.41	3.28
10 - 11	5.57E+09	17.86%	1.17E+08	20.29%	2.22E+06	30.66%	1.64E+07	28.16%	21.00	0.40	2.95
11 - 12	5.23E+09	21.14%	1.13E+08	24.29%	2.08E+06	34.33%	1.38E+07	31.04%	21.50	0.40	2.63
12 - 13	6.72E+09	25.34%	1.44E+08	29.41%	2.38E+06	38.54%	1.62E+07	34.43%	21.48	0.35	2.41
13 - 14	3.03E+09	27.24%	7.27E+07	32.00%	9.63E+05	40.24%	2.00E+06	34.84%	23.98	0.32	0.66
14 - 15	3.03E+09	29.14%	7.27E+07	34.58%	9.62E+05	41.95%	1.99E+06	35.26%	23.98	0.32	0.66
15 - 16	3.04E+09	31.04%	7.28E+07	37.16%	9.65E+05	43.65%	2.02E+06	35.68%	23.96	0.32	0.66
16 - 17	1.01E+10	37.35%	1.79E+08	43.52%	2.98E+06	48.92%	2.34E+07	40.58%	17.80	0.30	2.33
17 - 18	2.89E+10	55.44%	4.67E+08	60.09%	8.37E+06	63.72%	8.01E+07	57.34%	16.15	0.29	2.77
18 - 19	4.88E+10	85.97%	7.71E+08	87.48%	1.41E+07	88.59%	1.39E+08	86.49%	15.82	0.29	2.86
19 - 20	2.24E+10	100.00%	3.53E+08	100.00%	6.46E+06	100.00%	6.45E+07	100.00%	15.73	0.29	2.88
Global Total	1.60E+11		2.82E+09		5.66E+07		4.78E+08		17.63	0.35	2.99

Table G-6. Fuel burned, emissions, cumulative fractions of emissions, and emission indices as a function of altitude (Summed over Latitude and Longitude) for the Mach 2.0 (Nominal EI(NOx)=15) HSCT fleet only, assuming passenger demand corresponding to 500 Mach 2.4 HSCTs flying on the 1993 AESA assessment network. (revised from NASA CR 4592)

Altitude Band (km)	Fuel (kg/year)	cum fuel (%)	NOx (kg/year)	cum NOx (%)	HC (kg/year)	cum HC (%)	CO (kg/year)	cum CO (%)	EI(NOx)	EI(HC)	EI(CO)
0 - 1	2.11E+09	2.52%	3.11E+07	2.12%	2.55E+06	8.81%	2.39E+07	9.75%	14.77	1.21	11.35
1 - 2	7.76E+08	3.45%	1.67E+07	3.25%	4.30E+05	10.30%	2.71E+06	10.85%	21.54	0.55	3.50
2 - 3	7.76E+08	4.38%	1.67E+07	4.39%	4.30E+05	11.79%	2.71E+06	11.96%	21.54	0.55	3.50
3 - 4	7.76E+08	5.30%	1.67E+07	5.53%	4.30E+05	13.27%	2.71E+06	13.06%	21.54	0.55	3.50
4 - 5	7.76E+08	6.23%	1.67E+07	6.67%	4.30E+05	14.76%	2.71E+06	14.17%	21.54	0.55	3.50
5 - 6	7.76E+08	7.16%	1.67E+07	7.80%	4.30E+05	16.25%	2.71E+06	15.27%	21.54	0.55	3.50
6 - 7	7.76E+08	8.09%	1.67E+07	8.94%	4.30E+05	17.74%	2.71E+06	16.38%	21.54	0.55	3.50
7 - 8	7.76E+08	9.02%	1.67E+07	10.08%	4.30E+05	19.22%	2.71E+06	17.48%	21.54	0.55	3.50
8 - 9	1.15E+09	10.39%	2.41E+07	11.72%	5.56E+05	21.15%	3.90E+06	19.07%	21.06	0.49	3.40
9 - 10	2.48E+09	13.35%	5.24E+07	15.29%	9.88E+05	24.56%	7.04E+06	21.94%	21.18	0.40	2.84
10 - 11	2.80E+09	16.70%	5.97E+07	19.35%	1.09E+06	28.32%	7.56E+06	25.03%	21.31	0.39	2.70
11 - 12	2.90E+09	20.17%	6.24E+07	23.60%	1.11E+06	32.17%	7.35E+06	28.02%	21.54	0.38	2.54
12 - 13	3.82E+09	24.74%	8.15E+07	29.14%	1.33E+06	36.78%	9.46E+06	31.88%	21.32	0.35	2.47
13 - 14	1.51E+09	26.55%	3.64E+07	31.62%	4.76E+05	38.42%	9.38E+05	32.26%	24.02	0.31	0.62
14 - 15	1.51E+09	28.37%	3.64E+07	34.09%	4.76E+05	40.07%	9.38E+05	32.65%	24.02	0.31	0.62
15 - 16	1.52E+09	30.18%	3.65E+07	36.58%	4.78E+05	41.72%	9.54E+05	33.03%	23.99	0.31	0.63
16 - 17	7.01E+09	38.57%	1.19E+08	44.71%	2.05E+06	48.81%	1.77E+07	40.25%	17.04	0.29	2.53
17 - 18	1.75E+10	59.46%	2.79E+08	63.67%	5.04E+06	66.25%	4.92E+07	60.32%	15.96	0.29	2.82
18 - 19	2.53E+10	89.76%	3.99E+08	90.84%	7.30E+06	91.48%	7.27E+07	89.96%	15.76	0.29	2.87
19 - 20	8.56E+09	100.00%	1.35E+08	100.00%	2.47E+06	100.00%	2.46E+07	100.00%	15.73	0.29	2.88
Global Total	8.36E+10		1.47E+09		2.89E+07		2.45E+08		17.58	0.35	2.94

Appendix H. Altitude Distribution of Emissions for Year 2015 subsonic fleets

This appendix contains the tables which summarize the different Year 2015 subsonic emission scenarios occurring with fleets of 0, 500, and 1000 Mach 2.4 HSCTs. For each of the scenarios considered, the fuel burned and emissions (NOx, CO, and hydrocarbons) were summed over latitude and longitude and tabulated as a function of altitude in 1 km altitude increments (the resolution of the data set).

Cumulative fractions of fuel burned and emissions were calculated from the ground up to provide a simple way to evaluate how the emissions were distributed vertically. In addition, the effective emission index for each altitude band was calculated and tabulated.

The global total of fuel burned and emissions were calculated and listed at the bottom of each table. Also, included is the effective emission index for NOx, CO, and hydrocarbons, globally averaged over all locations and altitudes.

For the charts shown, the notation 1.00E+08 is equivalent to 1.00×10^8. The emissions are in units of kilograms per year and the emission indices have units of grams of emissions per kilogram of fuel burned.

US Standard Atmosphere (1976) pressures and temperatures were used in the calculations. These altitudes correspond to the geopotential (pressure) altitudes of the US Standard Atmosphere grid.

Table H-1. Fuel burned, emissions, cumulative fractions of emissions, and emission indices as a function of altitude (Summed over Latitude and Longitude) for the 2015 scheduled subsonic passenger fleet, assuming 500 Mach 2.4 HSCTs are flying on the universal network.

Altitude Band (km)	Fuel (kg/year)	cum fuel (%)	NOx (kg/year)	cum NOx (%)	HC (kg/year)	cum HC (%)	CO (kg/year)	cum CO (%)	EI(NOx)	EI(HC)	EI(CO)
0 - 1	2.61E+10	11.78%	2.50E+08	12.20%	3.06E+07	32.80%	3.40E+08	32.44%	9.56	1.17	12.99
1 - 2	6.95E+09	14.91%	8.75E+07	16.47%	6.37E+06	39.62%	6.03E+07	38.20%	12.59	0.92	8.67
2 - 3	6.09E+09	17.65%	7.48E+07	20.12%	5.44E+06	45.44%	5.13E+07	43.10%	12.29	0.89	8.43
3 - 4	7.81E+09	21.17%	1.05E+08	25.22%	4.94E+06	50.72%	4.52E+07	47.43%	13.38	0.63	5.79
4 - 5	6.68E+09	24.18%	8.18E+07	29.21%	5.47E+06	56.58%	4.71E+07	51.93%	12.25	0.82	7.06
5 - 6	6.11E+09	26.93%	7.26E+07	32.76%	4.52E+06	61.42%	4.72E+07	56.44%	11.89	0.74	7.73
6 - 7	5.19E+09	29.26%	5.98E+07	35.68%	3.63E+06	65.31%	4.05E+07	60.30%	11.53	0.70	7.80
7 - 8	5.52E+09	31.75%	6.09E+07	38.65%	3.99E+06	69.58%	4.37E+07	64.48%	11.03	0.72	7.93
8 - 9	6.13E+09	34.51%	6.54E+07	41.84%	4.23E+06	74.11%	4.58E+07	68.86%	10.67	0.69	7.48
9 - 10	6.73E+09	37.54%	6.67E+07	45.09%	4.17E+06	78.57%	4.39E+07	73.05%	9.91	0.62	6.52
10 - 11	4.32E+10	57.02%	3.39E+08	61.62%	6.44E+06	85.47%	9.47E+07	82.10%	7.83	0.15	2.19
11 - 12	9.54E+10	100.00%	7.86E+08	100.00%	1.36E+07	100.00%	1.87E+08	100.00%	8.24	0.14	1.96
Global Total	2.22E+11		2.05E+09		9.34E+07		1.05E+09		9.23	0.42	4.71

Table H-2. Fuel burned, emissions, cumulative fractions of emissions, and emission indices as a function of altitude (Summed over Latitude and Longitude) for the 2015 scheduled subsonic passenger fleet assuming 1000 Mach 2.4 HSCTs are flying on the universal network.

Altitude Band (km)	Fuel (kg/year)	cum fuel (%)	NOx (kg/year)	cum NOx (%)	HC (kg/year)	cum HC (%)	CO (kg/year)	cum CO (%)	EI(NOx)	EI(HC)	EI(CO)
0 - 1	2.48E+10	12.61%	2.32E+08	12.83%	2.92E+07	33.56%	3.27E+08	33.46%	9.32	1.18	13.18
1 - 2	6.66E+09	15.99%	8.24E+07	17.40%	6.11E+06	40.57%	5.81E+07	39.39%	12.36	0.92	8.71
2 - 3	5.83E+09	18.95%	7.03E+07	21.29%	5.19E+06	46.54%	4.93E+07	44.43%	12.05	0.89	8.46
3 - 4	7.41E+09	22.72%	9.71E+07	26.68%	4.72E+06	51.95%	4.34E+07	48.86%	13.10	0.64	5.85
4 - 5	6.40E+09	25.97%	7.70E+07	30.95%	5.25E+06	57.97%	4.52E+07	53.49%	12.03	0.82	7.07
5 - 6	5.84E+09	28.93%	6.81E+07	34.72%	4.29E+06	62.90%	4.53E+07	58.12%	11.67	0.74	7.76
6 - 7	4.93E+09	31.43%	5.55E+07	37.80%	3.41E+06	66.82%	3.89E+07	62.09%	11.26	0.69	7.88
7 - 8	5.24E+09	34.09%	5.64E+07	40.93%	3.75E+06	71.13%	4.19E+07	66.37%	10.77	0.72	8.00
8 - 9	5.81E+09	37.04%	6.05E+07	44.29%	3.96E+06	75.68%	4.38E+07	70.85%	10.43	0.68	7.54
9 - 10	6.31E+09	40.25%	6.13E+07	47.68%	3.90E+06	80.15%	4.18E+07	75.12%	9.71	0.62	6.62
10 - 11	3.89E+10	59.99%	2.97E+08	64.17%	5.84E+06	86.86%	8.77E+07	84.09%	7.65	0.15	2.26
11 - 12	7.88E+10	100.00%	6.46E+08	100.00%	1.14E+07	100.00%	1.56E+08	100.00%	8.20	0.15	1.98
Global Total	1.97E+11		1.80E+09		8.71E+07		9.78E+08		9.16	0.44	4.97

Table H-3. Fuel burned, emissions, cumulative fractions of emissions, and emission indices as a function of altitude (Summed over Latitude and Longitude) for the 2015 scheduled subsonic passenger fleet assuming no HSCTs are flying on the universal network.

Altitude Band (km)	Fuel (kg/year)	cum fuel (%)	NOx (kg/year)	cum NOx (%)	HC (kg/year)	cum HC (%)	CO (kg/year)	cum CO (%)	EI(NOx)	EI(HC)	EI(CO)
0 - 1	2.73E+10	10.92%	2.67E+08	11.51%	3.18E+07	32.05%	3.49E+08	31.44%	9.78	1.17	12.79
1 - 2	7.20E+09	13.80%	9.22E+07	15.49%	6.57E+06	38.66%	6.19E+07	37.01%	12.80	0.91	8.60
2 - 3	6.32E+09	16.33%	7.92E+07	18.90%	5.63E+06	44.33%	5.29E+07	41.78%	12.53	0.89	8.38
3 - 4	8.18E+09	19.60%	1.12E+08	23.71%	5.13E+06	49.50%	4.68E+07	45.99%	13.65	0.63	5.72
4 - 5	6.92E+09	22.37%	8.61E+07	27.42%	5.67E+06	55.20%	4.87E+07	50.37%	12.45	0.82	7.03
5 - 6	6.35E+09	24.91%	7.68E+07	30.73%	4.73E+06	59.96%	4.87E+07	54.75%	12.10	0.74	7.67
6 - 7	5.44E+09	27.08%	6.41E+07	33.49%	3.82E+06	63.81%	4.20E+07	58.53%	11.79	0.70	7.72
7 - 8	5.78E+09	29.40%	6.52E+07	36.30%	4.21E+06	68.05%	4.53E+07	62.61%	11.27	0.73	7.84
8 - 9	6.42E+09	31.97%	7.00E+07	39.31%	4.47E+06	72.55%	4.75E+07	66.88%	10.90	0.70	7.40
9 - 10	7.50E+09	34.97%	7.53E+07	42.56%	4.45E+06	77.02%	4.62E+07	71.04%	10.04	0.59	6.15
10 - 11	5.04E+10	55.13%	4.04E+08	59.95%	7.30E+06	84.37%	1.06E+08	80.54%	8.01	0.14	2.09
11 - 12	1.12E+11	100.00%	9.29E+08	100.00%	1.55E+07	100.00%	2.16E+08	100.00%	8.28	0.14	1.93
Global Total	2.50E+11		2.32E+09		9.94E+07		1.11E+09		9.28	0.40	4.44

Table H-4. Fuel burned, emissions, cumulative fractions of emissions, and emission indices as a function of altitude (Summed over Latitude and Longitude) for the 2015 scheduled subsonic cargo fleet (unchanged from NASA Contractor Report 4592)

Altitude Band (km)	Fuel (kg/year)	cum fuel (%)	NOx (kg/year)	cum NOx (%)	HC (kg/year)	cum HC (%)	CO (kg/year)	cum CO (%)	EI(NOx)	EI(HC)	EI(CO)
0 - 1	4.24E+08	7.52%	4.04E+06	8.23%	1.05E+06	29.38%	7.36E+06	26.59%	9.52	2.47	17.35
1 - 2	1.04E+08	9.35%	1.33E+06	10.94%	1.84E+05	34.54%	1.24E+06	31.07%	12.81	1.77	11.97
2 - 3	1.02E+08	11.16%	1.36E+06	13.72%	1.95E+05	40.00%	1.26E+06	35.64%	13.32	1.90	12.36
3 - 4	1.30E+08	13.46%	1.78E+06	17.34%	1.64E+05	44.61%	1.12E+06	39.69%	13.71	1.27	8.65
4 - 5	9.27E+07	15.10%	1.15E+06	19.68%	1.71E+05	49.41%	1.14E+06	43.81%	12.36	1.84	12.30
5 - 6	9.62E+07	16.81%	1.15E+06	22.03%	1.78E+05	54.39%	1.17E+06	48.03%	11.99	1.85	12.16
6 - 7	9.69E+07	18.52%	1.15E+06	24.36%	1.76E+05	59.33%	1.13E+06	52.13%	11.83	1.82	11.70
7 - 8	1.05E+08	20.39%	1.15E+06	26.72%	1.93E+05	64.76%	1.22E+06	56.53%	10.97	1.84	11.59
8 - 9	1.12E+08	22.36%	1.17E+06	29.11%	1.91E+05	70.12%	1.19E+06	60.84%	10.52	1.71	10.68
9 - 10	1.11E+08	24.33%	1.10E+06	31.36%	2.00E+05	75.75%	1.20E+06	65.19%	9.94	1.81	10.86
10 - 11	6.54E+08	35.92%	5.71E+06	42.99%	2.38E+05	82.43%	1.94E+06	72.21%	8.72	0.36	2.97
11 - 12	3.62E+09	100.00%	2.80E+07	100.00%	6.26E+05	100.00%	7.69E+06	100.00%	7.73	0.17	2.13
Global Total	5.64E+09		4.91E+07		3.56E+06		2.77E+07		8.69	0.63	4.90

Appendix I. 3-Dimensional Scenario Data Format

The three dimensional emission scenario data files calculated by Boeing were delivered to NASA Langley electronically in a slightly different format than that used previously (Ref. 1). In addition to fuel and emissions, the total miles flown within in a cell is also provided. The format is now:

i, j, k; fuel(lb/day); NOx(lb/day); CO(lb/day); HC(lb/day); distance (nautical miles/day)

Only non-zero values are included in the ASCII data files.

Altitude:

Index k — means emissions in the band from altitude k to k+1
i.e. index 19 is emissions in the 19-20 km band
Values run from 0 to 22

Latitude:

Index i — means emissions in the band from latitude i to i+1
values run from 0 to 179

For i<=89 northern hemisphere
index 0 is emissions from equator to 1 degree N

For i>=90 southern hemisphere
index 90 is emissions from equator to 1 degree S
index 179 is emissions from 89S-90S

Longitude: Wrap all the way around the globe.

Index j — means emissions in the longitude band j to j+1
values run from 0 to 359

For j<=179 east of prime meridian
index 0 is emissions from 0-1E
index 179 is emissions from 179E-180E

For j>=180 west of prime meridian
index 180 is emissions from -180W - -179W
index 359 is emissions from -1W - 0

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13. ABSTRACT *(Maximum 200 words)*
This report describes the development of a three-dimensional database of aircraft fuel burn and emissions (fuel burned,NOx, CO, and hydrocarbons) from projected fleets of high speed civil transports (HSCTs) on a universal airline network. Inventories for 500 and 1000 HSCT fleets, as well as the concurrent subsonic fleets, were calculated.

The objective of this work was to evaluate the changes in geographical distribution of the HSCT emissions as the fleet size grew from 500 to 1000 HSCTs. For this work, a new expanded HSCT network was used and flights projected using a market penetration analysis rather than assuming equal penetration as was done in the earlier studies. Emission inventories on this network were calculated for both Mach 2.0 and Mach 2.4 HSCT fleets with NOx cruise emission indices of approximately 5 and 15 grams NOx/kilogram fuel.

These emissions inventories are available for use by atmospheric scientists conducting the Atmospheric Effects of Stratospheric Aircraft (AESA) modeling studies. Fuel burned and emissions of nitrogen oxides (NOx as NO2), carbon monoxide, and hydrocarbons have been calculated on a 1 degree latitude x 1 degree longitude x 1 kilometer altitude grid and delivered to NASA as electronic files.

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